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DEVELOPMENT OF A PAVEMENT MAINTENANCE MANAGEMENT SYSTEM VOLUME VIII: DEVELOPMENT OF AN AIRFIELD PAVEMENT MAINTENANCE AND REPAIR CONSEQUENCE SYSTEM

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This report documents development of the Airfield Pavement Management System (APMS), a computerized system for analyzing airfield pavements. The system provides: (1) a method for determining feasible maintenance and repair (M&R) alternatives for a given pavement feature, (2) a procedure for performing economic analyses to compare various M&R alternatives for a given pavement feature, and (3) a procedure for forecasting the Pavement Condition Index and key distresses as a consequence of applying an M&R alternative to a particular pavement feature.

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20 ABSTRACT (CONCLUDED)

APMS now consists of seven modules designed to: (1) perform evaluation summary, (2) perform localized repair analysis, (3) evaluate the consequences of localized repair, (4) evaluate the consequences of other M&R, (5) perform cost analysis, (6) perform benefit analysis, and (7) perform budget optimization.

PREFACE

This investigation was performed for the Headquarters, Air Force Engineering&Services Center, HQAFESC/RDCF, Tyndall Air Force Base, Florida, under Reimbursable Order No. S-80-7. The AFESC/RDCF Project Officer was Lt. R. McDonald.

This investigation was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL) during the period from January 1980 to April 1981. Dr. R. Quattrone is Chief of the Engineering and Materials Division.

Colonel Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

This technical report has been reviewed and is approved for publication.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). It will be available at NTIS to the general public, including foreign nations.

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SECTION I

INTRODUCTION

1. BACKGROUND

An airfield pavement maintenance management system has been under development for the U.S. Air Force for the past several years (References 1 through 7). The first part of the system to be developed was the Pavement Condition Index (PCI) -- a distress composite index that represents the pavement's structural integrity and operational surface condition (References 1 through 5). It has been adopted and fully implemented by the U.S. Air Force.

Since the PCI was introduced in 1976, three other procedures for pavement maintenance management have been developed:

a. A method for determining feasible Maintenance and Repair (M&R) alternatives for a given pavement feature. This procedure is based on the PCI, distress data, and other relevant pavement evaluation factors, such as structural capacity and roughness (References 3 and 6).

b. A procedure for performing economic analyses to compare various M&R alternatives for a given pavement feature (References 3 and 6).

c. A procedure for forecasting PCI and key distresses as a consequence of applying an M&R alternative to a particular pavement feature (Reference 7). The forecasting models developed under this procedure are considered preliminary since they are currently being evaluated and improved.

The U.S. Air Force has identified a need to interface and computerize these three procedures in a user-oriented, interactive system -- the Airfield Pavement Management System (APMS).

2. OBJECTIVE

The overall objective of the work documented in this report was to interface and computerize the three pavement maintenance management procedures to form APMS. Specific objectives were to:

a. Conceive the overall design of the consequence system.

b. Develop or refine the procedures to be used in the system.

c. Computerize each element of the system in a user-oriented, interactive form.

3. APPROACH

These objectives were accomplished as follows:

a. Previous research had led to the development of most of the procedures needed in the consequence system (References 1 through 7). This research provided a foundation for the concept of the overall system. The system was designed to comprise seven computational modules, each of which was to contain a separate pavement maintenance and management procedure. All modules were interfaced in a logical sequence.

b. Procedures for budget optimization had to be developed since they were not available from previous research.

c. Finally, all the necessary procedures and specifications for a user-oriented computer system were developed and used to program the system.

4. REPORT ORGANIZATION

Section II of this report provides an overview of APMS and briefly introduces each of its modules. Sections III through IX present detailed descriptions of each module and provide computerized examples of input and output routines. However, a complete documentation of the computer code is not presented since this report is not intended to be a user's manual.

SECTION II

OVERVIEW OF APMS

APMS is a group of computation or evaluation modules used to analyze factors such as the effect of localized repair, the cost of an M&R activity, or budget optimization at the project or network level. The system is intended to provide the user many tools with which to assess a pavement for cost and performance.

The APMS now has seven computation/analysis modules and one data storage module. Each one, except the data storage module, functions independently of the others.

The input of data to each module described below is done interactively with a computer terminal. The user is prompted by the system for the necessary data to run the module. A block diagram of the system is shown in Figure 1.

1. EVALUATION SUMMARY MODULE

This module provides a list of feasible general M&R alternatives from which the user can make specific choices about a given pavement feature (Section III). The user inputs information from the condition evaluation summary (Figure 2). The information is then processed through performance standards tables, and the M&R alternatives are produced.

2. LOCALIZED REPAIR ANALYSIS MODULE

The localized repair analysis module computes both the cost of a given localized repair policy and the PCI after repair (Section IV). This allows the user to compare localized repair alternatives on the basis of its effect on cost and condition.

The distress data from the condition survey are input as a sample unit. This information is then stored in a file and used by the module for cost and PCI calculations.

3. CONSEQUENCE OF LOCALIZED REPAIR MODULE

The consequence of localized repair module augments the information obtained in the localized repair analysis and is used to predict the PCI change with age after localized repair (Section V). This allows the performance of various localized repair alternatives to be analyzed.

4. CONSEQUENCE OF OVERALL REPAIR MODULE

The consequence of overall repair module is used to predict the performance of overall repair alternatives (Section VI). The module can also be

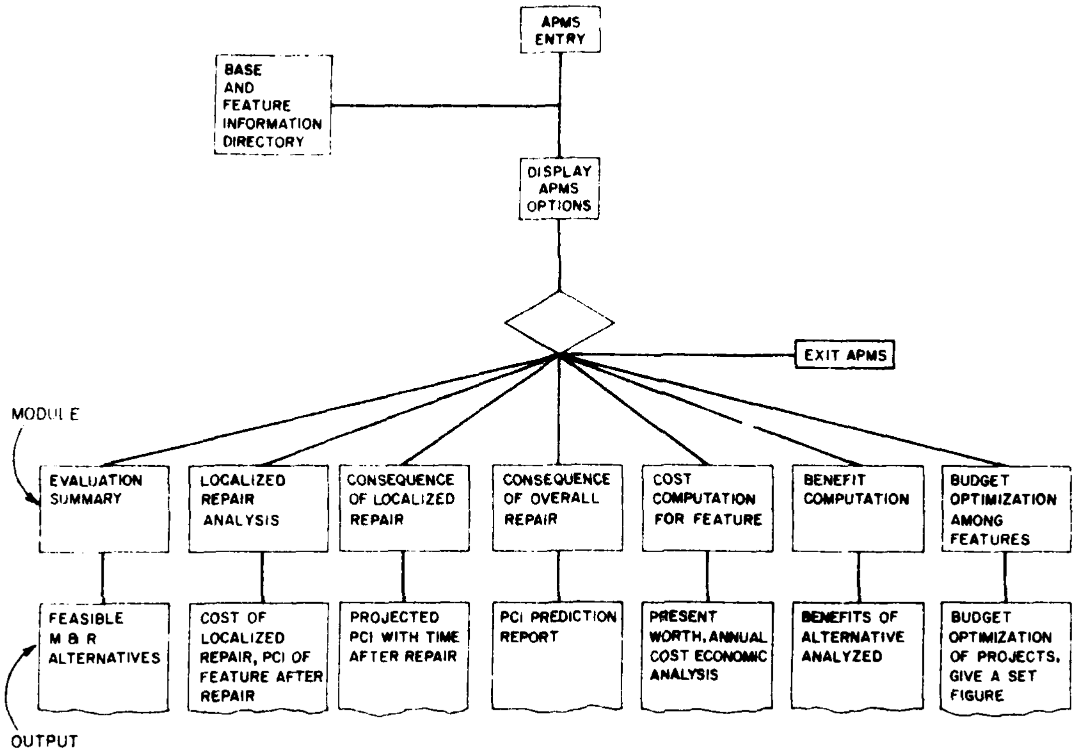

Figure 1. Overview of APMS

used to predict the future performance of a new pavement feature, or of an existing one, if overall maintenance is not done.

The PCI prediction models developed in FY79 are used in this module (Reference 7). These models shall be updated and improved periodically.

5. COST COMPUTATION MODULE

The cost computation module is used to perform life-cycle cost analyses on M&R alternatives selected for possible use on a specific feature (Section VIII).

The cost analysis used includes a present value analysis which provides the total cost of the alternative adjusted for interest and inflation rates. Also, an equivalent uniform-annual-cost analysis is computed; this distributes the cost annually over the life of the alternative.

6. BENEFIT COMPUTATION MODULE

The benefit computation module provides the user a method to calculate the benefit of a given M&R alternative in terms of its weighted performance (Section VIII).

Facility: ______________________ Feature: ______________________

1. Overall Condition Rating - PCI

Excellent, Very Good, Good, Fair, Poor, Very Poor, Failed.

2. Variation of Condition Within Section -- PCI

a. Localized Random Variation	Yes,	No	
b. Systematic Variation:	Yes,	No	

3. Rate of Deterioration of Condition - PCI

a. Long-term period (since construction)	Low,	Normal,	High
b. Short-term period (1 year)	Low,	Normal,	High

4. Distress Evaluation

a. Cause

Load Associated Distress	____percent deduct value
Climate/Durability Associated	____percent deduct value
Other (____) Associated Distress	____percent deduct value
b. Moisture (Drainage) Effect on Distress	Minor, Moderate, Major

5. Load-Carrying Capacity Deficiency — No, Yes

6. Surface Roughness — Minor, Moderate, Major

7. Skid Resistance/Hydroplaning (runways only) — No hydroplaning problems are expected

a. Mu-Meter	Transitional Potential for hydroplaning Very high probability
b. Stopping Distance Ratio	No hydroplaning anticipated Potential not well defined Potential for hydroplaning Very high hydroplaning potential
c. Transverse Slope	Poor, Fair, Good, Excellent

8. Previous Maintenance — Low, Normal, High

9. Effect on Mission (Comments: ______________________

____

____

____

____

Figure 2. Airfield Pavement Condition Evaluation Summary

The benefit of an alternative is calculated using the following parameters:

a. Area under PCI-time curve

b. Utility values (Figures 35 through 37)

c. Relative weights for feature type

d. Minimum PCI for the feature.

The benefit calculated in this module and the cost data from the cost computation module are then used as input to the budget optimization module.

7. BUDGET OPTIMIZATION MODULE

The purpose of this module is to maximize the benefits gained from budget dollars (Section IX). Using the cost and benefit figures for several M&R alternatives per feature, the budget optimization module performs calculations which select, for a group of pavement features, the set of M&R alternatives maximizing the benefits for a given budget.

SECTION III

EVALUATION SUMMARY MODULE (EVALSUM)

To select a specific M&R alternative for a given pavement feature, the engineer must evaluate several different M&R possibilities. When these options are listed, the pavement condition rating and other characteristics, such as rate of condition deterioration and load-carrying capacity, must be analyzed to obtain a set of M&R alternatives which are appropriate for further analysis.

The evaluation summary module (EVALSUM) has been developed to provide the engineer with a preliminary set of feasible M&R alternatives that would normally be recommended by experienced engineers. The list generated by the module is not meant to be all inclusive but is intended to provide a useful starting point. The engineer may combine items on the list or add or delete alternatives for further analysis before final selection of a specific M&R option.

1. DESCRIPTION

The inputs to EVALSUM are the PCI and condition evaluation summary data for a given feature (Figure 2). These data provide enough information to generate a preliminary list without considering features peculiar to individual projects.

The first step in developing the module was to select a set of alternatives that would provide the engineer with a sound base from which a set of options for a specific project could be conceptualized. The 14 alternatives shown in Table 1 are those finally selected for use in the system.

During research for Volume VI of Development of an Airfield Pavement Maintenance Management System (Reference 6), it was found that the PCI scale could be broken down into four M&R zones (Figure 3). From the PCI-based M&R zones and the condition evaluation summary data, the performance standards tables concept was developed to combine these data and generate a list of alternatives. Performance standards tables were produced for all M&R zones (Tables 2 through 5).

The performance standards tables were constructed by considering a typical pavement feature in a given M&R zone and then placing the M&R alternatives that would be considered for each item on the evaluation sheet. The alternatives not to be considered were selected similarly. For example, Table 3 is used for features with a PCI range of 40 to 70. If the evaluation summary showed no load deficiency, alternatives 3, 8, and 14 of Table 1 would be considered, but alternatives 2, 4, and 11 would be eliminated. The initial tables were reviewed by Air Force command engineers in July 1980. Their comments were then combined to form Tables 2 through 5.

After the performance standards tables were completed, the EVALSUM module was developed (Figure 4). For a given set of input data, the module determines the list of feasible M&R alternatives as follows:

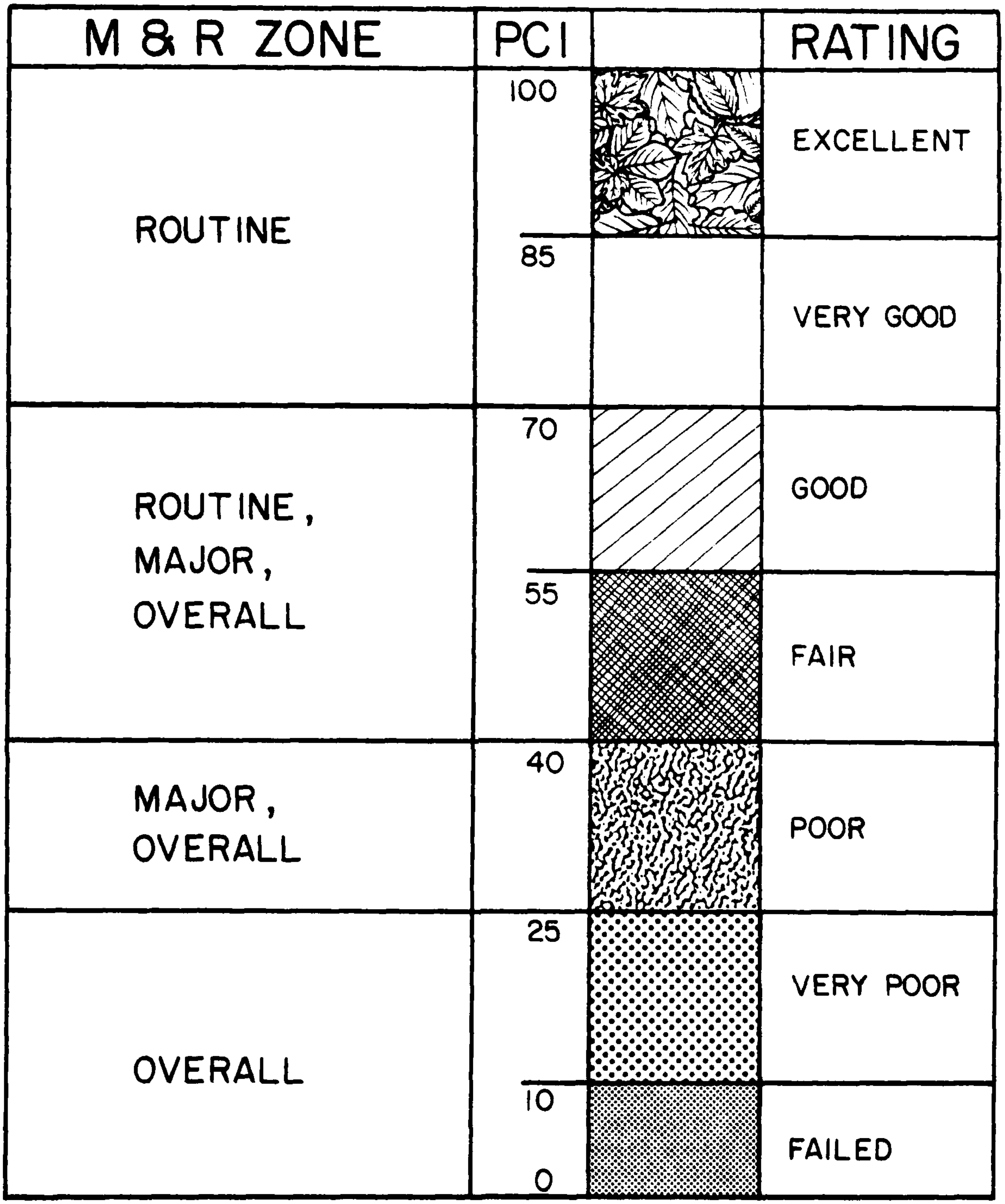

Figure 3. Correlation of M&R Zones With PCI and Condition Rating

TABLE 1. MAINTENANCE AND REPAIR ALTERNATIVES USED IN EVALSUM MODULE

Alternative Number	Description
1	Reconstruction
2	Structural overlay (asphalt-concrete)
3	Leveling overlay (asphalt-overlay) -- 2-inch nominal
4	PCC overlay
5	Grooving
6	Grinding
7	Porous friction surface
8	Surface treatment
9	Slab jacking
10	Surface recycling
11	Structure recycling
12	Redefine feature
13	Drainage modification
14	Routine maintenance

a. The appropriate performance standards table is selected based on the PCI value input.

b. A list of the feasible M&R alternatives is developed from the table based on the evaluation summary inputs.

c. A list of infeasible alternatives is also compiled.

d. The infeasible alternatives are then removed from the feasible list.

e. The remaining alternatives are output as the recommended maintenance options.

As previously stated, the list generated is not intended to be complete. However, the EVALSUM module should provide a set of M&R alternatives that most engineers would consider given similar data. Special conditions at a specific location may call for additional considerations.

2. EXAMPLE INPUT AND OUTPUT

The example of input and output is feature R3C from Pope Air Force Base, North Carolina. The feature evaluation summary data input is shown in Figure 2. The inputs are prompted by an interactive computer program. After data are input, they can be displayed as shown in Figure 5. The inputs are the lower case letters following the I> symbol. From these data, the feasible M&R alternatives report is generated. As shown in Figure 6, five alternatives were recommended. An actual project completed on R3C consisted of a combination of alternatives 11 and 2; i.e., recycling the structure and structural overlay.

TABLE 2. PCI RANGE 70 to 100

Item		Feasible Alternative*	Alternative Not To Be Considered*
Local Variation	Yes	14*	
	No	14	
Systematic Variation	Yes	12,14	
	No	14	
Rate of Deterioration, Short Term	Low	14	
	Normal	14	
	High	2,4,13,14	
Rate of Deterioration, Long Term	Low	14	
	Normal	14	
	High	14	
Distress Source	Load	14	
	Climate	14	
Load Deficiency	Yes	2,4,14	5,6,7
	No	14	
Roughness	Low	14	
	Medium	3,6,9,10,14	
	High	3,6,9,10	5,7
Skid	Low	14	
	Medium	3,5,6,7,8,10,14	
	High	3,5,6,7,8,10,14	
Previous Maintenance	Low	14	
	Normal	14	
	High	14	

*See Table 1 for key to this column.

TABLE 3. PCI RANGE 40 TO 70

Item		Feasible Alternative*	Alternative Not To Be Considered*
Local Variation	Yes	14	
	No	14	
Systematic Variation	Yes	12,14	
	No	14	
Rate of Deterioration, Short Term	Low	14	
	Normal	2,3,4,10,14	
	High	1,2,4,10,13	
Rate of Deterioration, Long Term	Low	14	
	Normal	2,3,4,10,14	
	High	1,2,4,10,14	
Distress Source	Load	1,2,3,4,11,14	
	Climate	3,8,10,14	
Load Deficiency	Yes	1,2,4	3,5,6,7,8,9,10,14
	No	3,8,14	2,4,11
Roughness	Low	14	
	Medium	3,6,9,10,14	
	High	3,6,9,10	5,7
Skid	Low	14	
	Medium	3,5,6,7,8,10,14	
	High	3,5,6,7,8,10,13	
Previous Maintenance	Low	14	
	Normal	14	
	High	10,11	3,5,6,7,14

*See Table 1 for key to this column.

TABLE 4. PCI RANGE 25 TO 40

Item		Feasible Alternative*	Alternative Not To Be Considered*
Local Variation	Yes	14	
	No	14	
Systematic Variation	Yes	1,2,4,12	
	No	14	
Rate of Deterioration, Short Term	Low	2,4,10,11,14	
	Normal	1,2,4,10,11	
	High	1,2,4,11	5,6,7,8
Rate of Deterioration, Long Term	Low	14	
	Normal	1,2,4,11,14	
	High	1,2,4,11	5,6,7,8
Distress Source	Load	1,2,4,11	3,5,6,7,14
	Climate	10,14	5,6
Load Deficiency	Yes	1,11	3,5,6,7,8,9,10
	No	3,10	
Roughness	Low	3,6,14	
	Medium	3,6,9	
	High	3,6,9	5,7,8
Skid	Low	3,5,14	
	Medium	3,5,10	
	High	3,5,7	4,14
Previous Maintenance	Low	14	
	Normal	2,4	5,14
	High	1,2,4	4,5,14

*See Table 1 for key to this column.

TABLE 5. PCI RANGE 0 TO 25

Item		Feasible Alternative*	Alternative Not To Be Considered*
Local Variation	Yes	1,2,4,10,11	
	No	1,2,4,10,11	
Systematic Variation	Yes	1,2,4,10,11	
	No	1,2,4,10,11	
Rate of Deterioration, Short Term	Low	1,2,4,10,11	
	Normal	1,2,4,10,11	
	High	1,2,4,10,11	
Rate of Deterioration, Long Term	Low	1,2,4	
	Normal	1,2,4	
	High	1,2,4	
Distress Source	Load	1,2,4,11	
	Climate	1,2,4,10	
Load Deficiency	Yes	1,2,4,11	10
	No	10	
Roughness	Low	1,2,11	
	Medium	1,2,11	
	High	1,2,11	
Skid	Low	2,11	
	Medium	1,2,11	
	High	1,2,11	
Previous Maintenance	Low	2,11	
	Normal	1,2,11	
	High	1,2,11	

*See Table 1 for key to this column.

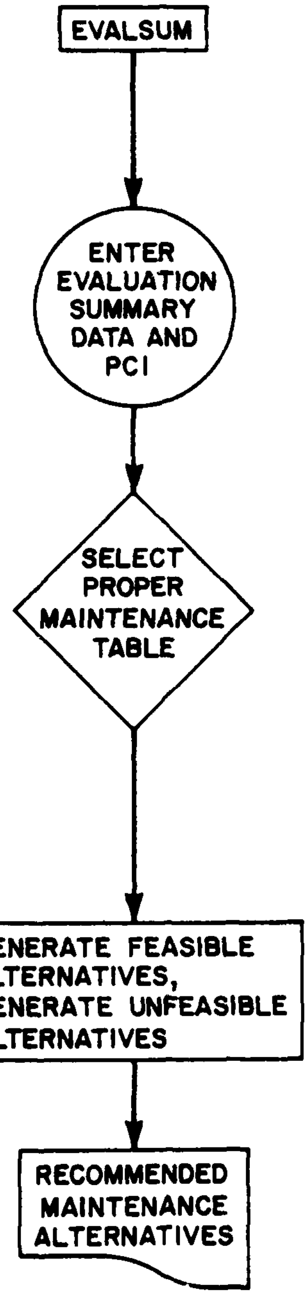

Figure 4. Block Diagram of EVALSUM Module

```
EVALUATION SUMMARY SELECTED:

ENTER PRESENT PCI :=
I>57
LOCAL VARIATION(Y/N) :=
I>n
SYSTEMATIC VARIATION(Y/N) :=
I>n
SHORT TERM RATE OF DETERIORATION(L,N,H) :=
I>h
LONG TERM RATE OF DETERIORATION(L,N,H) :=
I>n
MAJOR SOURCE OF DISTRESS(LOAD,CLIMATE) :=
I>load
LOAD CARRYING DEFICIENCY(Y,N) :=
I>y
SURFACE ROUGHNESS(L,M,H) :=
I>l
SKID/HYDROPLANING PROBLEMS(L,M,H) :=
I>l
PREVIOUS MAINTENANCE(L,N,H) :=
I>n
SELECT :=
     A := DISPLAY CURRENT VALUE OF ITEMS SELECTED
     B := CHANGE SELECTED ITEMS
     C := PRINT FEASIBLE ALTERNATIVES REPORT
     D := EXIT EVALUATION SUMMARY SUBSYSTEM
     H := DISPLAY OPTIONS
SELECT :=
I>a

CURRENT VALUES ARE AS FOLLOWS :=
 1  PCI :=  57
 2  LOCAL VARIATION(Y/N)      := N
 3  SYSTEMATIC VARIATION(Y,N) := N
 4  SHORT TERM RATE OF DETERIORATION(L,N,H):= H
 5  LONG TERM RATE OF DETERIORATION(L,N,H) := N
 6  MAJOR SOURCE OF DISTRESS(LOAD,CLIMATE) := L
 7  LOAD CARRYING DEFICIENCY(Y,N) := Y
 8  SURFACE ROUGHNESS(L,M,H)      := L
 9  SKID/HYDROPLANING PROBLEMS(L,M,H) := L
10  PREVIOUS MAINTENANCE(L,N,H)       := N
```

Figure 5. Input Data: Pope Air Force Base Feature R3C -- EVALSUM

```
DATE := 03 JAN 81          FEASIBLE M&R ALTERNATIVES

BASE := POPE AIR FORCE BASE         FEATID := R3C      PCI:=  57
FEATNM := RUNWAY S.END CENTER       M&R REPAIR ZONE := ROUTINE-MAJOR-OVERALL

          ***** RECOMMENDED MAINTENANCE ALTERNATIVES *****

           1 :=  RECONSTRUCTION
           2 :=  OVERLAY STRUCTURAL AC
           4 :=  OVERLAY PCC
          11 :=  RECYCLE STRUCTURE
          13 :=  DRAINAGE MODIFICATION

          *** END ***
```

Figure 6. Example EVALSUM Output

SECTION IV

ANALYSIS OF LOCALIZED REPAIR MODULE (ANALOC)

Analysis of localized repair is often the first step in selecting M&R alternatives. Before such analysis, PCIs and the effect of certain repair methods on pavement condition must be determined and the cost of repairs estimated. The analysis of localized repair module (ANALOC) was designed to provide this information.

1. DESCRIPTION

The ANALOC module works on a pavement feature basis. For a given feature, the system computes the PCI before repair, estimated PCI after repair, and cost estimate for the repairs. A simplified flow chart of the ANALOC module is shown in Figure 7. Once a condition survey has been performed on the pavement feature, each sample unit's distress data are input to the ANALOC module. These data are then processed through the PCI program. The data can be processed without modification to produce a PCI before repair or the data can be processed in combination with built-in M&R distress policy tables. The module allows the user to modify, temporarily or permanently, all built-in tables. A temporary change is in effect only while the module is being used for the analysis of a particular pavement feature. The distress to be repaired can be chosen individually, or the system will default to repair all distresses. The M&R policy routine produces a report which gives a breakdown of costs for each distress repaired and a total cost estimate. The distress-after-repair policy replaces the original distresses with those resulting when a repair is applied (or eliminates the distress when the repair dictates). The new distress types are inserted in the PCI calculation program, and a report is generated giving the new PCI and estimated quantities of distress. From these reports, the impact of the localized repair on the pavement condition and the associated costs are obtained.

The routines for M&R policy and distress-after-repair policy are explained in more detail below.

a. Maintenance and Repair Policy Routine

The M&R policy routine is composed of two elements: distress M&R policy tables and M&R cost data tables. Separate tables are used for asphalt and concrete pavements. The distress M&R policy tables relate distress-type and severity combinations to a specific repair code. These tables are built in the module and may be changed by the user on a temporary or permanent basis. There are 18 repair codes (9 for asphalt and 9 for concrete pavements); these are shown in Tables 6 and 7. The user constructs a policy table by assigning a specific repair code to a combination of distress type and severity. A brief example of a policy for concrete pavements is shown in Table 8. If entries are not made for all distress types, the system defaults to the do nothing alternatives for those combinations not entered. The distress-repair code combinations are monitored through allowable policy tables for asphalt and concrete pavements (Tables 9 and 10). These tables provide a listing of the repair codes that are considered feasible for the

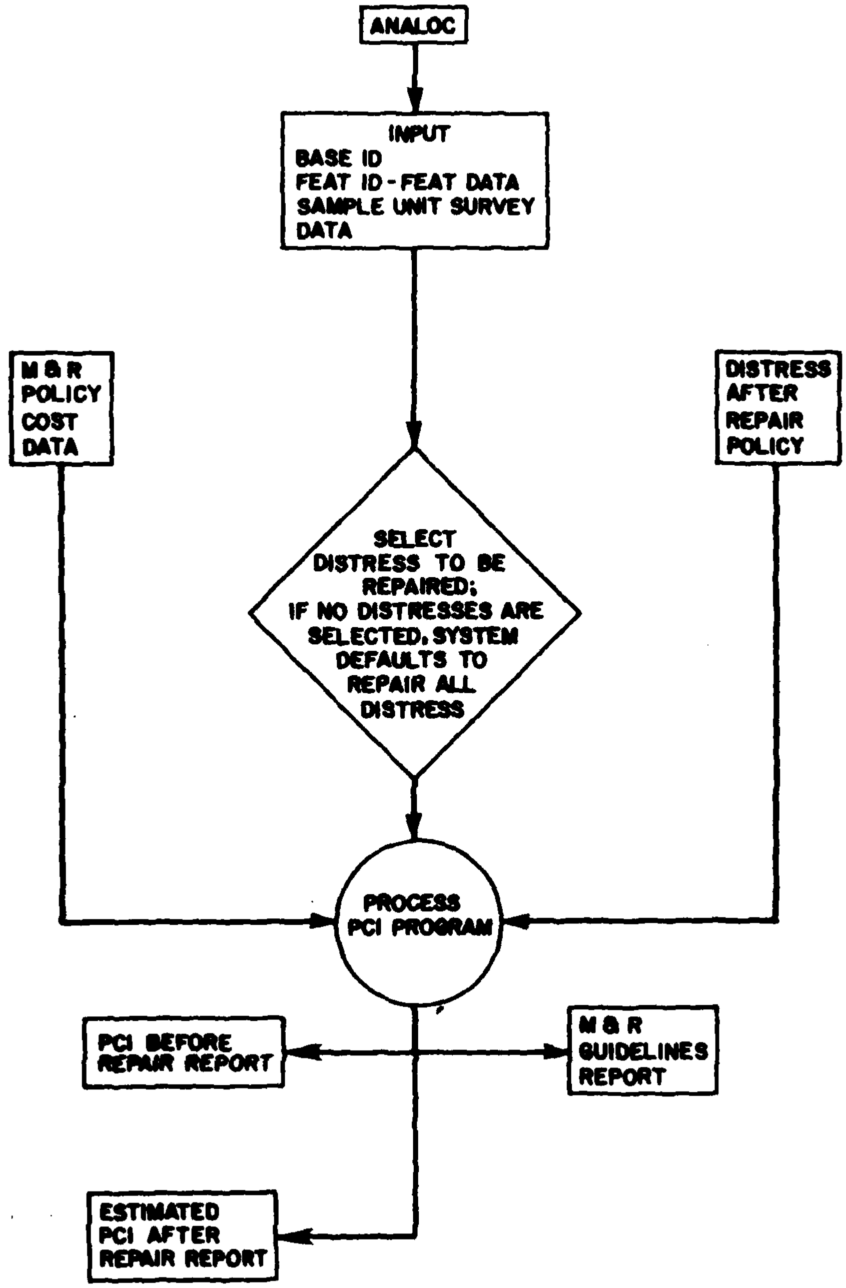

Figure 7. Simplified Flowchart of ANALOC Module

TABLE 6. KEY TO REPAIR CODE -- CONCRETE PAVEMENTS

Repair Code	Repair Type	Units
1	Do nothing	—
2	Crack seal	Linear feet
3	Joint seal	Linear feet
4	Partial depth patch	Square feet
5	Full depth patch	Square feet
6	Slab replacement	Square yards
7	Underseal	Number of slabs
8	Grinding slab	Square feet
9	Slab jack — grout	Number of slabs

TABLE 7. KEY TO REPAIR CODES -- ASPHALT PAVEMENTS

Repair Code	Repair Type	Units
1	Do nothing	—
2	Crack seal	Linear feet
3	Partial depth patch	Square feet
4	Full depth patch	Square feet
5	Skin patch	Square feet
6	Apply heat and roll sand	Square yards
7	Apply surface seal (emulsion)	Square yards
8	Apply rejuvenator	Square yards
9	Apply aggregate seal	Square yards

TABLE 8. EXAMPLE M&R POLICY TABLE -- CONCRETE PAVEMENTS

Distress Code	Distress Type	Severity Level	Repair Code
3	Longitudinal/transverse/diagonal crack	M*	2
4	Durability cracking	H	5
6	Small patch	L	1
		M	2
		H	4
9	Pumping	—	7

* M = Medium
L = Low
H = High

TABLE 9. ALLOWABLE ASPHALT PAVEMENT MAINTENANCE POLICY

Distress Code	Distress Type	Severity	Repair Code*	Distress Code	Distress Type	Severity	Repair Code*
1	Alligator crack	L*	1,8	10	Batching	L	1
1		M	1,3,4,8	10		M	1,2
1		H	1,3,4	10		H	1,3,4
2	Bleeding	—	1,6	11	Polish aggregrate	--	1,9
3	Block crack	L	1,2,8,9	12	Weathering/ raveling	L	1,7,8
3		M	1,2,9	12		M	1,7,9
3		M	1,2,9	12		M	1,7,9
3		H	1,2	12		H	1,3,9
4	Corrugation	L	1	13	Rutting	L	1
4		M	1,3,4	13		M	1,3,4,5
4		H	1,3,4	13		H	1,3,4,5
5	Depression	L	1	14	Shoving	L	1
5		M	1,3,4,5	14		M	1,3
5		H	1,3,4,5	14		H	1,3
6	Jet blast	—	1,3,5,7,9	15	Slippage crack	—	1,3
7	Joint reflection crack	L	1,2	16	Swelling	L	1
7		M	1,2	16		M	1,4
7		H	1,2,3	16		H	1,4
8	Longitudinal/transverse crack	L	1,2,8,9				
8		M	1,2,9				
8		H	1,2,3,9				
9	Oil spillage	—	1,3,4				

* L = Low
M = Medium
H = High

*See Table 7 for repair code key.

TABLE 10. ALLOWABLE CONCRETE PAVEMENT MAINTENANCE POLICY

Distress Code	Distress Type	Severity Level	Repair Code*	Distress Code	Distress Type	Severity Level	Repair Code*
1	Blow-up	L*	1,4	10	Sealing	L	1
1		M	1,4	10		M	1,4
1		H	1,5,6	10		H	1,4,6
2	Corner break	L	1,2	11	Faulting	L	1
2		M	1,3,5	11		MM	1,8,9
2		H	1,2,5	11		H	1,6,8,9
3	Longitudinal/transverse diagonal crack	L	1,2	12	Shattered slab	1,2,6	
3		M	1,2	12		M	1,2,6
3		H	1,2,4,5,6	12		H	1,2,6
4	D crack	L	1,2,3	13	Shrinkage crack	---	1
4		M	1,4,5	14	Joint	L	1,3,4
4		H	1,4,5,6	14	Spall	M	1,3,4,5,6
5	Joint seal damage	L	1	14		H	1,4,5,6
5		M	1,3	15	Corner	L	1,3
5		H	1,3	15	Spall	M	1,3,4
6	Small patch	L	1	15		H	1,4
6		M	1,2,4				
6		H	1,4,5				
7	Large patch	L	1				
7		M	1,2,4				
7		H	1,4,5,6				
8	Popouts	---	1				
9	Pumping	---	1,2,3,7				

* L = Low
M = Medium
H = High

distress-severity combinations. Any combination which is not shown in the tables is not allowed as input.

The M&R cost data tables contain the cost information associated with each repair type. A sample cost data table is shown in Table 11. If a cost breakdown is not available, the user may insert total cost only. Once distresses to be repaired have been selected, the distress M&R policy table is scanned and the proper cost identified. The unit costs from the tables are further multiplied by the "cost location factor" to adjust them for a specific location. For example, if a base in a certain geographical area had unit costs which were 25 percent higher than the average (stored in tables), the cost location factor would be 1.25. The expense of repairing the pavement feature is then computed from the distress data for the feature. This computation uses the repair units listed in Tables 6 and 7. It is imperative that the cost data correspond to these units; otherwise, the user will get incorrect results.

b. Distress-After-Repair Routine

The distress-after-repair routine stored in the APMS system is shown in Tables 12 and 13. These tables, which contain the distress severity after repair for each distress-repair code combination, may be modified by the user temporarily or permanently.

The distress-after-repair routine works as follows:

(1) Once distress-repair combinations have been selected, the routine scans the appropriate table and identifies the distress severity after repair.

(2) The new distress severity is then inserted in the sample unit data, replacing the original distress. The quantity of distress remains the same -- except when a distress is eliminated. In this case, the distress and quantity are removed from the sample units where they appear.

(3) Having placed all the distress-after-repair values in the sample unit data, the routine executes the PCI calculation program.

TABLE 11. EXAMPLE M&R COST DATA TABLE -- ASPHALT PAVEMENT

Repair Code	Repair Type	Repair Unit	Labor, Hours	Labor, Dollars per Unit	Equipment, Dollars per Unit	Materials, Dollars per Unit	Total
1	Do nothing	--	0.00	0.00	0.00	0.00	0.00
2	Crack filling	Linear feet	0.125	0.80	0.20	0.75	1.75

TABLE 12. CONSEQUENCE OF M&R ALTERNATIVES FOR LOCALIZED AND PREVENTIVE METHODS ON ASPHALT AND TAR-SURFACED PAVEMENTS

	REPAIR CODE								
	1. Do Nothing	2. Crack Seal	3. Partial Depth Patch	4. Full Depth Patch	5. Skin Patch	6. Apply Heat and Roll Sand	7. Apply Surface Seal (Emulsion)	8. Apply Rejuvenator	9. Apply Aggregate Seal Coat
1L	1L	11	10L	10L	10L	1L	X	1L	X
1M	1M	1M	10L	10L	10L	1M	X	2L	X
1H	1H	1H	10L	10L	10L	1H	X	3L	X
2	2	2	10L	10L	10L	X	X	2	X
3L	3L	3L	10L	10L	10L	3L	X	3L	X
3M	3M	3L	10L	10L	10L	3M	X	3M	X
3H	3H	3H	10L	10L	10L	3H	X	3H	X
4L	4L	4L	10L	10L	10L	4L	4L	4L	4L
4M	4M	4M	10L	10L	10L	4M	4M	4M	4M
4H	4H	4H	10L	10L	10L	4H	4H	4H	4H
5L	5L	5L	10L	10L	10L	5L	5L	5L	5L
5M	5M	5M	10L	10L	10L	5M	5M	5M	5M
5H	5H	5H	10L	10L	10L	5H	5H	5H	5H
6	6	6	10L	10L	10L	6	X	6	X
7L	7L	7L	10L	10L	10L	7L	X	7L	X
7M	7M	7L	10L	10L	10L	7M	X	7M	X
7H	7H	7L	10L	10L	10L	7H	X	7H	X
8L	8L	8L	10L	10L	10L	8L	X	8L	X
8M	8M	8L	10L	10L	10L	8M	X	8M	X
8H	8H	8L	10L	10L	10L	8H	X	8H	X
9	9	9	10L	10L	10L	9	X	9	X
10L	10L	10L	10L	10L	10L	10L	X	10L	X
10M	10M	10M	10L	10L	10L	10M	X	10M	X
10H	10H	10H	10L	10L	10L	10H	X	10H	X

TABLE 12. CONSEQUENCE OF M&R ALTERNATIVES FOR LOCALIZED AND PREVENTIVE METHODS ON ASPHALT AND TAR-SURFACED PAVEMENTS (CONCLUDED)

	REPAIR CODE								
	1. Do Nothing	2. Crack Seal	3. Partial Depth Patch	4. Full Depth Patch	5. Skin Patch	6. Apply Heat and Roll Sand	7. Apply Surface Seal (Emulsion)	8. Apply Rejuvenator	9. Apply Aggregate Seal Coat
11	11	11	10L	10L	10L	11	X	11	X
12L	12L	12L	10L	10L	10L	12L	X	X	X
12M	12M	12M	10L	10L	10L	12M	X	12L	X
12H	12H	12H	10L	10L	10L	12H	X	12M	X
13L	13L	13L	10L	10L	10L	13L	13L	13L	13L
13M	13M	13M	10L	10L	10L	13M	13M	13M	13M
13H	13H	13H	10L	10L	10L	13H	13H	13H	13H
14L	14L	14L	10L	10L	10L	14L	14L	14L	14L
14M	14M	14M	10L	10L	10L	14M	14L	14M	14L
14H	14H	14H	10L	10L	10L	14H	14L	14H	14L
15	15	15	10L	10L	10L	15	X	15	X
16L	16L	16L	10L	10L	10L	16L	16L	16L	16L
16M	16M	16M	10L	10L	10L	16M	16M	16M	16M
16H	16H	16H	10L	10L	10L	16H	16H	16H	16H

X = Distress eliminated
L = Distress at low severity
M = Distress at medium severity
H = Distress at high severity

1 = Alligator crack
2 = Bleeding
3 = Block crack
4 = Corrugation
5 = Depression
6 = Jet blast
7 = Joint reflection crack
8 = Longitudinal and transverse crack
9 = Oil spillage
10 = Patching
11 = Polished aggregate
12 = Raveling/weathering
13 = Rutting
14 = Shoving
15 = Slippage crack
16 = Swelling

TABLE 13. CONSEQUENCE OF M&R ALTERNATIVES FOR LOCALIZED AND PREVENTIVE METHODS ON JOINTED CONCRETE PAVEMENTS

	REPAIR CODE								
	1. Do Nothing	2. Crack Sealing	3. Joint Sealing	4. Partial Depth Patch (Bonded)	5. Full Depth Patch	6. Slab Replacement	7. Underseal	8. Grounding Slab	9. Slab Jack-Grout
1L	1L	1L	1L	7L	7L	X	1L	1L	1L
1M	1M	1M	1M	7L	7L	X	1M	1M	1M
1H	1H	1H	1H	1H	7L	X	1H	1H	1H
2L	2L	2L	2L	6L	7L	X	2L	2L	2L
2M	2M	2L	2M	6L	7L	X	2M	2M	2M
2H	2H	2L	2H	6L	7L	X	2H	2H	2H
3L	3L	3L	3L	7L	7L	X	3L	3L	3L
3M	3M	3L	3M	7L	7L	X	3M	3M	3M
3H	3H	3L	3H	7L	7L	X	3H	3H	3H
4L	4L	4L	4L	7L	7L	X	4L	4L	4L
4M	4M	4M	4M	7L	7L	X	4M	4M	4M
4H	4H	4H	4H	7L	7L	X	4H	4H	4H
5L	5L	5L	X	5L	5L	5L	5L	5L	5L
5M	5M	5M	X	5M	5M	5M	5M	5M	5M
5H	5H	5H	X	5H	5H	5H	5H	5H	5H
6L	6L	6L	6L	6L	6L	X	6L	6L	6L
6M	6M	6M	6M	6L	6L	X	6M	6M	6M
6H	6H	6H	6H	6L	6L	X	6H	6H	6H
7L	7L	7L	7L	7L	7L	X	7L	7L	7L
7M	7M	7M	7M	7L	7L	X	7M	7M	7M
7H	7H	7H	7H	7L	7L	X	7H	7H	7H
8	8	8	8	6L	6L	X	8	8	8
9	9	X	X	9	9	X	X	9	X

TABLE 13. CONSEQUENCE OF M&R ALTERNATIVES FOR LOCALIZED AND PREVENTIVE METHODS ON JOINTED CONCRETE PAVEMENTS (CONCLUDED)

REPAIR CODE

	1. Do Nothing	2. Crack Sealing	3. Joint Sealing	4. Partial Depth Patch (Bonded)	5. Full Depth Patch	6. Slab Replacement	7. Underseal	8. Grounding Slab	9. Slab Jack-Grout
10L	10L	10L	10L	7L	7L	X	10L	X	10L
10M	10M	10M	10M	7L	7L	X	10M	X	10M
10H	10H	10H	10H	7L	7L	X	10H	X	10H
11L	11L	11L	11L	11L	11L	X	X	X	X
11M	11M	11M	11M	11M	11M	X	X	X	X
11H	11H	11H	11H	11H	11H	X	X	X	X
12L	12L	12L	12L	12L	7L	X	12L	12L	12L
12M	12M	12M	12M	12M	7L	X	12M	12M	12M
12H	12H	12M	12H	12H	7L	X	12H	12H	12H
13	13	13	13	13	7L	X	13	13	13
14L	14L	14L	14L	6L	6L	X	14L	14L	14L
14M	14M	14L	14L	7L	7L	X	14M	14M	14M
14H	14H	14M	14M	7L	7L	X	14H	14H	14H
15L	15L	15L	15L	6L	6L	X	15L	15L	15L
15M	15M	15L	15L	6L	6L	X	15M	15M	15M
15H	15H	15M	15M	7L	7L	X	15H	15H	15H

X = Distress eliminated
L = Distress at low severity
M = Distress at medium severity
H = Distress at high severity

1 = Blow-up
2 = Corner break
3 = Longitudinal/transverse/diagonal crack
4 = "D" crack
5 = Joint seal damage
6 = Small patch less than 5 feet
7 = Large patch greater than 5 feet
8 = Popouts
9 = Pumping
10 = Crazing/sealing
11 = Settling/faulting
12 = Divided slab
13 = Shri kage crack
14 = Spai ng joint
15 = Spa ng corner

(4) The distress summary and PCI after repair for the pavement feature are calculated by the program and printed as output at the user's command. The PCI report resulting from the distress-after-repair routine provides the user with estimates of the PCI and of distress after repair.

2. SAMPLE PROBLEM

A test feature was developed to demonstrate the ANALOC module. Feature 1 is an asphalt section having two sample units with the distresses as shown in Table 14.

The repair policy and costs used for Test Feature 1 analysis are shown in Table 15. The interactive series necessary to produce the reports is shown in Figure 8 (user inputs follow the I symbol), while Figures 9a and 9b present the actual reports. Figure 9a is a detailed PCI report before repair, while Figure 9b is the summary PCI after repair and the estimated cost of repair. It can be seen that the localized repair of Test 1 would increase the PCI from 45 to 71 at a cost of $5815.

At this point, the user may wish to see the results of a different set of localized repairs. One way to do this would be to select specific distresses for repair rather than using the option of repairing all distresses. For the sample problem it was decided to try repairing only medium severity block cracking (3M) and medium severity longitudinal/transverse cracking (8M). The repair policy and unit costs remained the same. The process of identifying the distresses for repair is shown in Figure 10, and the resulting output in Figure 11.

This analysis shows that the PCI could be raised about 5 points (45 to 50) for an estimated cost of $581.

```
 WELCOME TO AIRFIELD PAVEMENT MANAGEMENT SYSTEM(APMS)
 ENTER (6 CHAR) BASEID:
I>STARR
 ASSIGNED STARR  := TEST BASE
 SELECT A DIFFERENT BASE ID (Y/N)?
I>N
 THERE ARE CURRENTLY    1 FEATURES ASSIGNED
 ENTER (6 CHAR) FEATID:
I>TEST1
 ASSIGNED TEST1  := APMS TEST
 SELECT(A-J):=            H=HELP
I>B
LOCALIZED REPAIR ANALYSIS FOR TEST1 :
1  DATE OF SURVEY(MM.DD.YY) :=   12.29.80
2  PAVEMENT TYPE(A OR P)    :=     A
3  FEATURE SIZE(SQFT)     :=   10000
5  TOTAL NMBR SAMPLE UNITS IN FEATURE :=          2
6  ALLOWABLE ERROR OF PCI             :=          5
7  COST LOCATION FACTOR               :=       1.25
CHANGE ABOVE INFORMATION (Y/N)?
I>N
ENTER SAMPLE ID#   (CR TO EXIT)
I>
```

Figure 8. Interactive Series Used in Obtaining PCI and M&R Reports

TABLE 14. TEST FEATURE INFORMATION FOR USE IN ANALOC MODULE

Base name: Test Base
Feature name: Test 1
Feature identification: Test 1

Date of survey: 12/29/80
Pavement type: asphalt

Feature size: 10,000 square feet

Total number of sample units: 2

Cost location factor: 1.25

Sample unit: 001
Sample size: 5000 square feet
Sample Type: random

Distress	Severity	Quantity
01-alligator cracking	L*	400
01-alligator cracking	M	200
03-block cracking	M	600

Sample unit: 002
Sample size: 5000 square feet
Sample tpe: random

Distress	Severity	Quantity
03-longitudinal/ transverse cracking	M	200
03-block cracking	H	500

PCI before repair: 45
Rating: fair

* L = Low
M = Medium
H = High

TABLE 15. REPAIR POLICY AND COSTS FOR TEST FEATURE 1

MAINTENANCE AND REPAIR POLICY LIST

Distress Code	Severity Level	Description	Repair Code	Repair Method
1	L	Alligator crack	1	Do nothing
1	M	Alligator crack	3	Partial depth patch
3	M	Block crack	9	Apply aggregate seal coat
3	H	Block crack	2	Crack seal
8	M	Longitudinal/transverse crack	2	Crack seal

REPAIR POLICY UNIT COSTS

Repair Code	Repair Method	Unit	Labor, Hours	Labor, Cost	Materials	Equipment	Total Cost
1	Do nothing	—	0.000	0.000	0.000	0.000	0.000
2	Crack seal	Linear feet	0.000	0.000	0.000	0.000	1.500
3	Partial depth patch	Square feet	0.000	0.000	0.000	0.000	20.000
4	Full depth patch	Square feet	0.000	0.000	0.000	0.000	35.000
5	Skin patch	Square feet	0.000	0.000	0.000	0.000	0.000
6	Apply heat and roll sand	Square yards	0.000	0.000	0.000	0.000	0.000
7	Apply surface seal	Square yards	0.000	0.000	0.000	0.000	0.000
8	Apply rejuvenator	Square yards	0.000	0.000	0.000	0.000	0.000
9	Apply aggregate seal coat	Square yards	0.000	0.000	0.000	0.000	2.500

```
SELECT (A - F) :=
I>B
BEGIN PCI REPORT :=
-----------------------------------------------------------------

DATE SURVEYED 12/29/80.    FEATURE APMS TEST

    FEATURE SIZE :=                                  10000  SF

    TOTAL NO OF SAMPLE UNIT :=          2

    ALLOWABLE ERROR WITH 95% CONFIDENCE :=     5

         SAMPLE UNIT ID :=    1
         AREA OF SAMPLE,SF %  5000
         NO. OF SLABS IN SAMPLE :=

DISTRESS-TYPE       SEVERITY        QUANTITY        DENSITY %    DEDUCT VALUE
    01                LOW              400              8.00            40.7
    01                MEDIUM           200              4.00            44.0
    03                MEDIUM           600             12.00            25.2

                                                             PCI =   32

         SAMPLE UNIT ID :=    2
         AREA OF SAMPLE,SF %  5000
         NO. OF SLABS IN SAMPLE :=

DISTRESS-TYPE       SEVERITY        QUANTITY        DENSITY %    DEDUCT VALUE
    03                HIGH             500             10.00            42.0
    08                MEDIUM           200              4.00            22.4

                                                             PCI =   57

    NO. OF RANDOM SAMPLE :=             2

    NO. OF ADDITIONAL SAMPLE :=         0

PCI OF FEATURE              =  45    RATING = FAIR

RECOMMEND EVERY SAMPLE UNITS TO BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE :  ASPHALT PAVEMENT

DISTRESS-TYPE       SEVERITY        QUANTITY        DENSITY %    DEDUCT VALUE
    01                LOW              400              4.00            34.0
    01                MEDIUM           200              2.00            36.5
    03                MEDIUM           600              6.00            20.1
    03                HIGH             500              5.00            33.9
    08                MED'UM           200              2.00            16.3
-----------------------------------------------------------------
              FEATURE                              PCI         RATING

         APMS TEST                                  45          FAIR
```

a. Detailed PCI Report Before Repair

Figure 9. PCI and M&R Report Outputs

```
SELECT (A - F) :=
I>C
BEGIN PCI REPORT :=

-------------------------------------------------------------------

DATE SURVEYED 12/29/80.     FEATURE APMS TEST

PCI OF FEATURE =  71     RATING = V. GOOD

ESTIMATED DISTRESS FOR FEATURE : ASPHALT PAVEMENT

DISTRESS-TYPE       SEVERITY       QUANTITY       DENSITY %     DEDUCT VALUE
     01               LOW            400             4.00           24.0
     03               LOW            500             5.00           13.9
     08               LOW            200             2.00            8.0
     10               LOW            200             2.00            5.8

-------------------------------------------------------------------
```

```
SELECT (A - F) :=
I>E
BEGIN MRG REPORT :=

DATE :=  30 NOV 81      MAINTENANCE AND REPAIR GUIDELINES
BASEID := STARR                                FEATID := TEST1
BASENM := TEST BASE                            FEATNM := APMS TEST
FEATURE AREA :=     10000 SQFT

DISTRESS      DIS DISTRESS-QTY   REPAIR CODE       LABOR LABOR MAT'L EQUIP TOTAL
TYPE          SEV REPAIR-QTY     REPAIR TYPE       HOURS COST$ COST$ COST$ COST$
--------------------------------------------------------------------------------
ALLIGATOR CR   L    400  SF      1
                                         -- POLICY IS DO NOTHING ALTERNATIVE

ALLIGATOR CR   M    200  SF      3
                    200  SF      P DEPTH PATCH       0.0     0     0     0  5000
BLOCK CR       M    600  SF      9
                     66  SY      AGG. SEAL           0.0     0     0     0   206
BLOCK CR       H    500  SF      2
                    125  LF      CRACK SEAL          0.0     0     0     0   234
L & T CR       M    200  SF      2
                    200  LF      CRACK SEAL          0.0     0     0     0   375
--------------------------------------------------------------------------------
                                     TOTALS          0.0     0     0     0  5815
```

b. Detailed PCI Report Before Repair

Figure 9. PCI and M&R Report Outputs (Concluded)

```
 SELECT(A-F):=           H=HELP
I >A
DISTRESS SELECTION     (CR TO EXIT)    (.LIST)
ENTER [DC SV] TO REPAIR:
I >3 M
        3 M := BLOCK CR                       SELECTED FOR REPAIR
ENTER [DC SV] TO REPAIR:
I>8 M
        8 M := LONGITUDINAL/TRANVERSE  SELECTED FOR REPAIR
ENTER [DC SV] TO REPAIR:
```

Figure 10. Interactive Process Used in Changing Distress To Be Repaired

```
 BEGIN PCI REPORT :=
 -------------------------------------------------------------------

 DATE SURVEYED 12/29/80.    FEATURE APMS TEST

 PCI OF FEATURE =  50    RATING = FAIR

 ESTIMATED DISTRESS FOR FEATURE : ASPHALT PAVEMENT

 DISTRESS-TYPE      SEVERITY       QUANTITY      DENSITY %    DEDUCT VALUE
     01              LOW             400            4.00          34.0
     01              MEDIUM          200            2.00          36.5
     03              HIGH            500            5.00          33.9
     08              LOW             200            2.00           8.0

 -------------------------------------------------------------------
 SELECT (A - F) :=
I >E
 BEGIN MRG REPORT :=

 DATE :=  30 NOV 81      MAINTENANCE AND REPAIR GUIDELINES
 BASEID := STARR                              FEATID := TEST1
 BASENM := TEST BASE                          FEATNM := APMS TEST
 FEATURE AREA :=     10000 SQFT

 DISTRESS     DIS DISTRESS-QTY   REPAIR CODE      LABOR LABOR MAT'L EQUIP TOTAL
 TYPE         SEV REPAIR-QTY     REPAIR TYPE      HOURS COST$ COST$ COST$ COST$
 ------------------------------------------------------------------------------
 BLOCK CR      M    600   SF     9
                     66   SY     AGG. SEAL          0.0     0     0     0   206
 L & T CR      M    200   SF     2
                    200   LF     CRACK SEAL         0.0     0     0     0   375
 ------------------------------------------------------------------------------
                                     TOTALS         0.0     0     0     0   581
 SELECT (A - F) :=
I >F
 SELECT(A-F):=           H=HELP
I>F
 SELECT(A-J):=           H=HELP
I>J
 END APMS SYSTEM
```

Figure 11. PCI and M&R Reports After Distress Repair Changes

SECTION V

CONSEQUENCE OF LOCALIZED REPAIR MODULE (CONLOC)

The impact of localized repair alternatives on the existing and future condition of the pavement must be assessed. In the ANALOC module, the PCI immediately after repair was determined. The performance of the repair scheme or its value over time must then be estimated; such analysis can be used to compare various localized alternatives in terms of their performance. The consequence of localized repair module (CONLOC) has been designed to provide this information.

1. DESCRIPTION

The CONLOC module is used to project the PCI over time for a given pavement feature after localized repair. The best method to predict the life of localized repair is a straight-line extrapolation of the PCI time curve. For example, assume a pavement feature was constructed at time 0 with a PCI of 100; the present PCI of the feature is 55 (Figure 12). If a localized maintenance activity were applied which raised the PCI to a value of 70, the future PCI could be estimated by extrapolating the PCI time line, at the same slope as the original, from the PCI after repair. In this example, the original slope is 4.5 PCI points per year. Thus, the PCI 10 years after the repair is

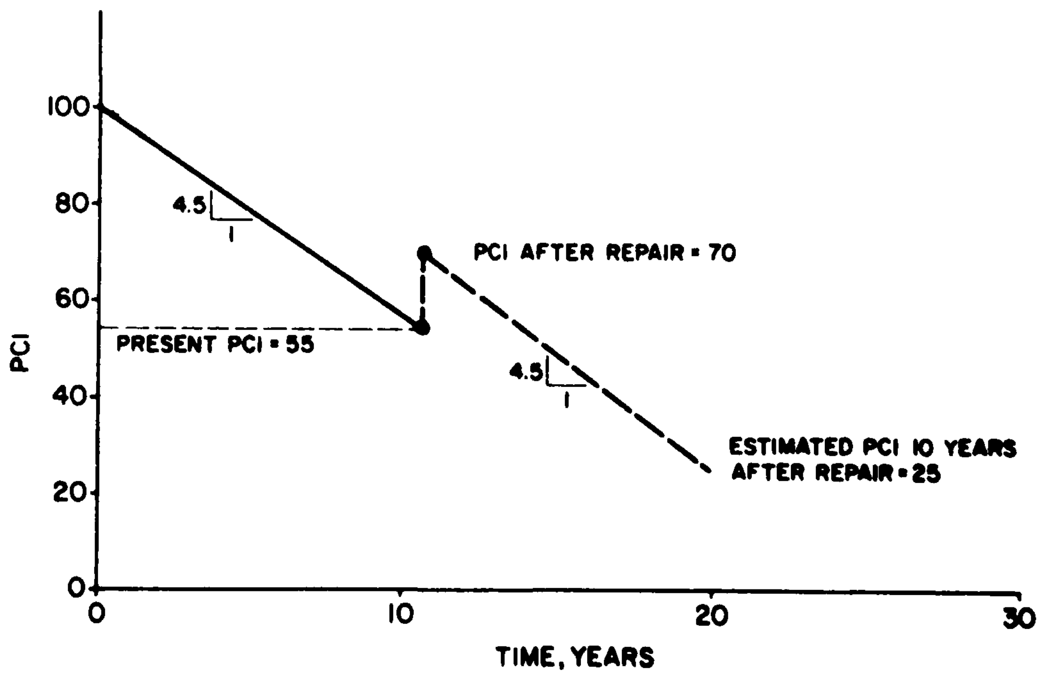

Figure 12. Example Extrapolation of PCI Time Line

determined by subtracting the prediction age (10 years) multiplied by the slope (4.5 points per year) from the PCI after repair (70). As shown in Figure 12, the estimated PCI after 10 years is 25; i.e., 70-10(4.5) = 25.

The equation used in the routine to model this performance is:

$$PCIP=PCIA-PA(K) \tag{1}$$

where:
- PCIP = predicted PCI
- PCIA = PCI after repair
- PA = prediction age; age is the time in years to present from original construction or last overlay
- K = slope of PCI time line from original construction or last overlay; K = (100-PCI present)/age.

If the PCI has been previously determined, the slope of the PCI time line between the previous PCI and the present PCI is computed. This slope is then compared with that of the PCI time line using the PCI at original construction, or the last overlay and the current PCI. The greatest slope helps predict the PCI after repair. Equation (1) is also used in this case, but the value K must be computed twice:

$$K_1=(100\text{-PCI present})/\text{age} \tag{2}$$

$$K_2 = (\text{PCI previous-PCI present})/\text{number of years} \tag{3}$$

where: number of years = time in years between present and previous PCI.

The greater value, K_1 or K_2, is then used in Equation (1) for the prediction of the future PCI. An example is shown in Figure 13.

Another option available in the CONLOC module is to consider the do nothing alternative. In this case, the slope of the PCI time line is extrapolated from the present PCI. This option allows the user to compare the other alternatives with the performance of the pavement if no maintenance activity were performed. A block diagram of the CONLOC module is shown in Figure 14.

2. EXAMPLE OF INPUT AND OUTPUT

Minimal information is needed to run the CONLOC module. Figure 15 gives the required inputs for a case in which the PCI has not been determined before. The values inserted after the line starting with I> are user input. The output for this example is Figure 16. As shown, both the do nothing and localized repair reports were selected. The prediction ages shown are from the present.

Figure 17 gives the inputs for a case in which a PCI has been determined previously. The only additional data required are the values of the previous PCI and the age between the previous and present PCIs. The output for the example is Figure 18.

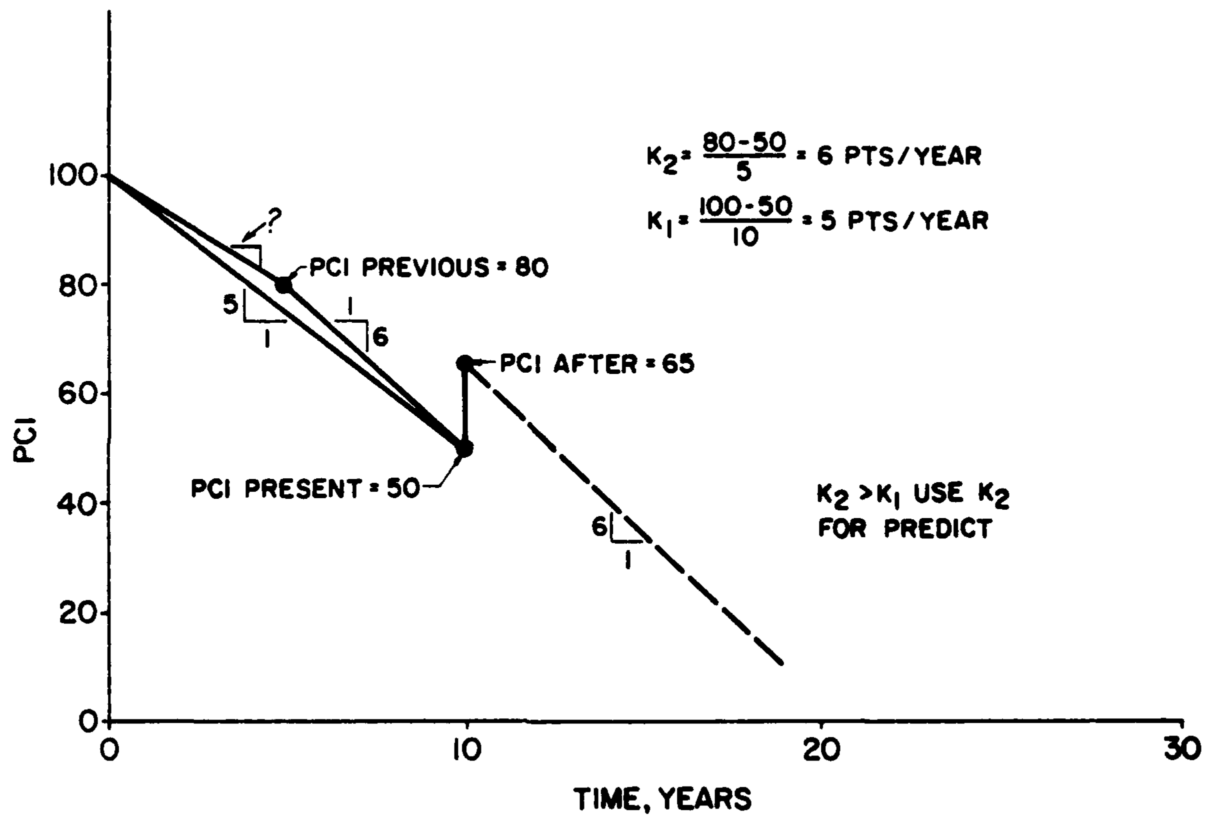

Figure 13. Example Case of PCI Prediction When PCI Was Previously Determined

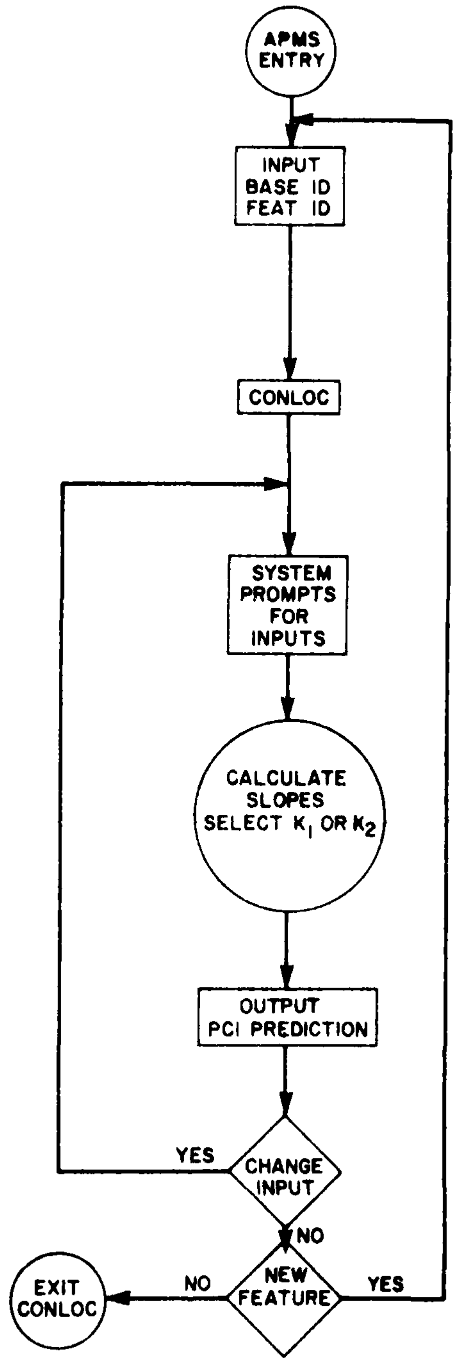

Figure 14. Block Diagram of CONLOC Module

```
CONSEQUENCE OF LOCALIZED REPAIR SELECTED:
ENTER AGE IN YEARS SINCE CONSTRUCTION OR OVERLAY(O NOT VALID):
I>10
ENTER PRESENT PCI(0-100):
I>45
HAS PCI BEEN PREVIOUSLY DETERMINED(Y/N)?
I>N
ENTER PCI AFTER REPAIR(0-100):
I>59
ENTER PREDICTION AGES IN YEARS FROM PRESENT
(SEPARATE BY SPACES, 10 AGES MAX:)
I>2 5 10
```

Figure 15. Input When PCI Has Not Been Previously Determined

```
DATE:=  24 NOV 81          CONSEQUENCE OF LOCALIZED REPAIR

BASEID:= STARR                      FEATID:= TEST1       PRESENT PCI:=    45
BASENM:= TEST BASE                  FEATNM:= APMS TEST

    AGE SINCE LOCALIZED
    MAINTENANCE APPLIED               PROJECTED PCI
            0                              59
            2                              48
            5                              31
           10                               4
SELECT(A-E):
I>D

DATE:=  24 NOV 81          CONSEQUENCE OF LOCALIZED REPAIR

BASEID:= STARR                      FEATID:= TEST1       PRESENT PCI:=    45
BASENM:= TEST BASE                  FEATNM:= APMS TEST

    DO NOTHING ALTERNATIVE
    PREDICTION AGES                     PROJECTED PCI
            0                              45
            2                              34
            5                              17
           10                               0
```

Figure 16. Output When PCI Has Not Been Previously Determined

```
CONSEQUENCE OF LOCALIZED REPAIR SELECTED:
ENTER AGE IN YEARS SINCE CONSTRUCTION OR OVERLAY(O NOT VALID):
I>10
ENTER PRESENT PCI(0-100):
I>45
HAS PCI BEEN PREVIOUSLY DETERMINED(Y/N)?
I>Y
ENTER PREVIOUS PCI (0-100):
I>80
ENTER AGE IN YEARS BETWEEN PRESENT & PREVIOUS PCI(O NOT VALID):
I>2
ENTER PCI AFTER REPAIR(0-100):
I>59
ENTER PREDICTION AGES IN YEARS FROM PRESENT
(SEPARATE BY SPACES, 10 AGES MAX:)
I>2 5 10
```

Figure 17. Input When PCI Has Been Previously Determined

```
SELECT:=
  A  :=  DISPLAY CURRENT VALUE OF ITEMS SELECTED
  B  :=  CHANGE SELECTED ITEMS
  C  :=  PRINT CONSEQUENCE OF LOCALIZED REPAIR REPORT
  D  :=  PRINT CONSEQUENCE OF THE DO NOTHING ALTERNATIVE
  E  :=  EXIT CONSEQUENCE SUBSYSTEM
  H  :=  DISPLAY OPTIONS
SELECT(A-E):
I>C

DATE:=  24 NOV 81              CONSEQUENCE OF LOCALIZED REPAIR

BASEID:= STARR                           FEATID:= TEST1        PRESENT PCI:=     45
BASENM:= TEST BASE                       FEATNM:= APMS TEST

    AGE SINCE LOCALIZED
    MAINTENANCE APPLIED                    PROJECTED PCI
             0                                  59
             2                                  24
             5                                   0
            10                                   0
SELECT(A-E):
I>D

DATE:=  24 NOV 81              CONSEQUENCE OF LOCALIZED REPAIR

BASEID:= STARR                           FEATID:= TEST1        PRESENT PCI:=     45
BASENM:= TEST BASE                       FEATNM:= APMS TEST

    DO NOTHING ALTERNATIVE
    PREDICTION AGES                          PROJECTED PCI
             0                                  45
             2                                  10
             5                                   0
            10                                   0
```

Figure 18. Output When PCI Has Been Previously Determined

SECTION VI

CONSEQUENCE OF OVERALL MAINTENANCE AND REPAIR MODULE (CONOMR)

To determine the consequence of overall repair, the future condition of the pavement with and without repair must be projected. Thus, the performance of a given pavement feature can be evaluated and the impact of various overall M&R strategies determined.

Figure 19 is a block diagram of the consequence of overall maintenance repair module (CONOMR). CONOMR is a computerized package of prediction models that have been under development since FY77. The models used in CONOMR are the equations presented in Volume VII of Development of a Pavement Maintenance Management System (Reference 7). Separate PCI prediction equations have been developed for asphalt concrete (AC) and portland cement concrete (PCC) pavements. The models are currently being evaluated and revised; as the models improve, they will be placed in the CONOMR module.

Predictions can be made for overall or major repairs, or for the do nothing alternative. The do nothing alternative prediction should always be performed because the results of the analysis are required in the benefit computation module (Section VIII).

1. CONCRETE PCI PREDICTION MODEL

The concrete prediction model is given by Equation (4); this model is used to analyze both concrete and asphalt-over-concrete pavements:

$$\begin{aligned} PCI = 100.0 - AGE[&0.01967\ FAT - 0.02408SR + \\ &0.001051\ (JSL \times JSS) + 0.9419\ ACOL\ 0.03475 \\ &PATCH + 2.91238 - 0.001775FI + 0.04066\ TEMP] \end{aligned} \tag{4}$$

where:

PCI = Pavement Condition Index at time AGE since construction or overlay with asphalt or concrete

AGE = time since construction of slab, or, if overlaid, time since overlay construction (years)

FAT = (ratio of interior slab stress/modulus of rupture) x 100

SR = slab replacement (percent total slabs)

JSL = longest joint spacing (feet)

JSS = shortest joint spacing (feet)

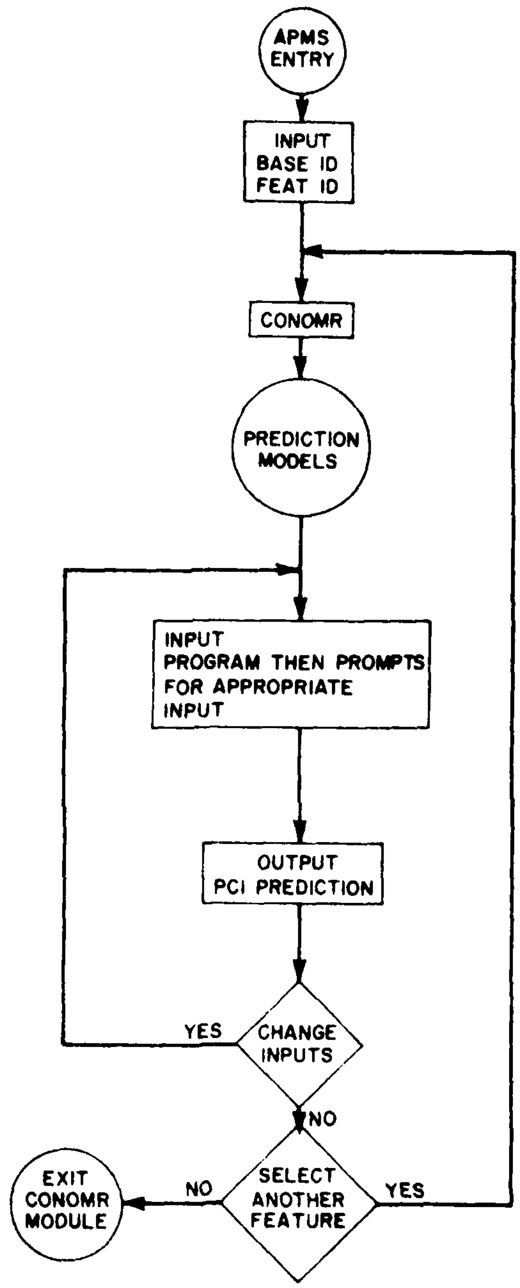

Figure 19. Block Diagram of CONOMR Module

ACOL = 1 if asphalt overlay exists
= 0 if no asphalt overlay exists

PATCH = slabs containing large patches (5 square feet), percent of total slabs, or percent area of total area patched if overlaid with asphalt

TEMP = average annual temperature (^{o}F)

FI = freezing index (degree days below $32^{o}F$).

The standard deviation of residuals from the equation is 10.5, and the R^2 is 0.37. The equation was developed based on data from 91 pavement features.

2. ASPHALT CONCRETE PCI PREDICTION MODEL

The asphalt concrete prediction model is a combined model that can be used to analyze pavements which have or have not been previously overlaid.

The PCI prediction model is shown in Equation (5):

$$PCI = 100 - AGE \left[\frac{1.487}{\alpha SG} + 0.143 \times AGECOL + \frac{6.56}{TAC} - 1.23\ \alpha_{AC}\right] \qquad (5)$$

where: AGE = time since original construction or since last overlay if the pavement has been overlaid

α_{SG} = load repetition factor determined at the subgrade level; α_{SG} is a function of total pavement thickness above the subgrade, subgrade California bearing ratio (CBR), and the tire contact area and tire pressure of an equivalent single wheel

AGECOL = age between the time the pavement was constructed and the time it received the last overlay; equals zero if the pavement was not overlaid

T_{AC} = total AC thickness in inches including overlay, if any

α_{AC} = load repetition factor determined at the AC base.

The standard deviation of residuals from the equation is 6.6 and the R^2 is .68. The equation was developed based on data from 37 pavement features.

3. EXAMPLE OF INPUT AND OUTPUT

a. Asphalt Pavement Example

The examples of input and output use the asphalt pavement structure in Figure 20. The do nothing option and a 2-inch overlay alternative are analyzed.

The inputs to evaluate the do nothing alternative are shown in Figure 21 (user inputs follow the I> symbol). Figure 22 is the predicted PCI report for the alternative. The values shown for the PCI are the expected values at the times given.

As shown, the PCI at 6 years is 61. If a 2-inch overlay were applied at this point, what would the resulting condition be? To analyze an overlay, the user inputs the age to overlay (6 years), the thickness of the overlay (2 inches), and the prediction ages after the overlay. The input and output for this procedure are shown in Figure 23. In this example, values of 0, 4, 9, and 14 years were selected; these values correspond to the 6-, 10-, 15-, and 20-year predictions of the do nothing alternative. These PCI values can be compared to evaluate the impact on the pavement's performance.

b. Concrete Pavement Examples

The structure of the concrete pavement is shown in Figure 24. In the example, the do nothing alternative and a slab replacement alternative are considered.

The inputs for the do nothing alternative are shown in Figure 25 (user inputs follow the I> symbol). The corresponding output showing the PCI prediction for the coming 20 years is in Figure 26.

The effect of replacement is analyzed by inputting slab age and percent of slabs to be replaced (Figure 27). The resulting PCI prediction is shown in Figure 28.

At this point, the user can change inputs or evaluate another repair, such as overlay.

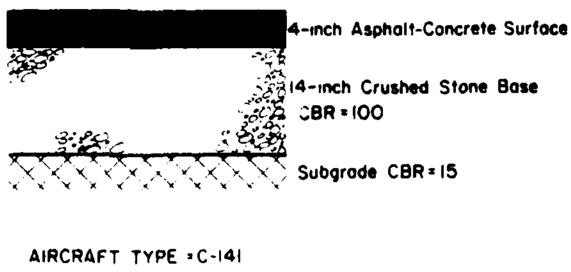

Figure 20. Example Pavement Section for Use in CONOMR Module

```
CONSEQUENCE OF OTHER M&R SELECTED
 ENTER PAVEMENT ID
I>TEST2
 ENTER PAVEMENT TYPE. AC OR PCC (A/P)
I>A
 HAS PCI BEEN PREVIOUSLY DETERMINED? (Y/N)
I>Y
 ENTER AGE IN YEARS AT WHICH PCI WAS DETERMINED [AGEPCI]
 MEASURED FROM LAST CONST/OVERLAY
I>6
 ENTER PCI VALUE [PCI]
I>61
 ENTER TIME IN YEARS BETWEEN ORIGINAL CONSTRUCTION [AGECOL]
 AND LAST OVERLAY (O IF NO OVERLAY)
I>0
 ENTER TOTAL AC THICKNESS IN INCHES INCLUDING OVERLAYS [TB]
I>4
 ENTER TOTAL PAVEMENT THICKNESS ABOVE SUBGRADE [TSG]
I>18
 ENTER CBR OF BASE [CBR-B]
I>100
 ENTER CBR OF SUBGRADE [CBR-SG]
I>15
 ENTER AIRCRAFT ID (OR "HELP") [ID]
I>C141

 ACCEPT,CHANGE,DISPLAY? (A/C/D)
I>A
 ENTER PREDICTION AGES SINCE LAST CONST/OVERLAY, SEPARATED BY COMMAS
I>0,6,10,15,20
```

Figure 21. Input for the Do Nothing Alternative for Asphalt Pavement

```
TEST2

     C141 AIRCRAFT ID
      0.0 AGE BETWEEN ORIGINAL CONSTRUCTION AND LAST OVERLAY
      4.0 TOTAL AC THICKNESS IN INCHES INCLUDING OVERLAYS
     18.0 TOTAL PAVEMENT THICKNESS ABOVE SUBGRADE
    100.0 CBR OF BASE
     15.0 CBR OF SUBGRADE
     61.0 PREDETERMINED PCI VALUE
      6.0 AGE AT WHICH PCI WAS DETERMINED AS MEASURED FROM
          LAST CONST/OVERLAY


  AGE SINCE LAST CONST/OVERLAY             PCI
  ----------------------------             ---
              0.0                         100.0
              6.0                          61.0
             10.0                          35.0
             15.0                           2.5
             20.0                           0.0
```

Figure 22. Predicted PCI Report for the Do Nothing Alternative for Asphalt Pavement

```
DO YOU WISH TO DETERMINE THE CONSEQUENCE ON PCI OF CHANGE IN
AIRCRAFT, OVERLAY, OR NONE? (A/O/N)
I>O
ENTER YEARS TO OVERLAY FROM LAST CONST/OVERLAY
I>6
ENTER OVERLAY THICKNESS
I>2
ENTER PREDICTION AGES SINCE OVERLAY, SEPARATED BY COMMAS
I>0,4,9,14


  TEST2

      C141 AIRCRAFT ID
       0.0 AGE BETWEEN ORIGINAL CONSTRUCTION AND LAST OVERLAY
       4.0 TOTAL AC THICKNESS IN INCHES INCLUDING OVERLAYS
      18.0 TOTAL PAVEMENT THICKNESS ABOVE SUBGRADE
     100.0 CBR OF BASE
      15.0 CBR OF SUBGRADE
      61.0 PREDETERMINED PCI VALUE
       6.0 AGE AT WHICH PCI WAS DETERMINED AS MEASURED FROM
           LAST CONST/OVERLAY

       6.0 YEARS TO OVERLAY FROM LAST CONST/OVERLAY
       2.0 THICKNESS OF OVERLAY


    AGE SINCE OVERLAY         PCI
    -----------------         ---
           0.0               100.0
           4.0                75.9
           9.0                45.9
          14.0                15.8
```

Figure 23. Input and Output for Asphalt Pavement

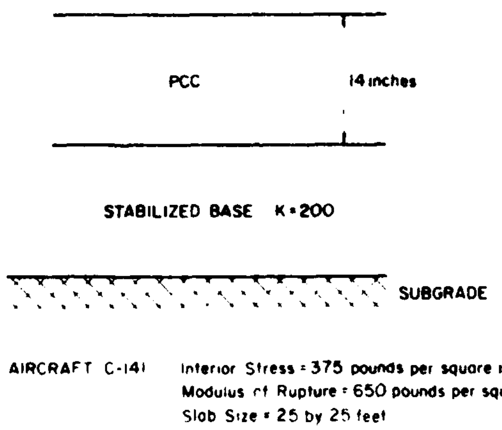

Figure 24. Pavement Structure Used in Concrete Example of CONOMR Module

```
 CONSEQUENCE OF OTHER M&R SELECTED
 ENTER PAVEMENT ID
I>TEST2
 ENTER PAVEMENT TYPE. AC OR PCC (A/P)
I>P
 HAS PCI BEEN PREVIOUSLY DETERMINED? (Y/N)
I>N
 ENTER % OF TOTAL SLABS REPLACED [SR]
I>0
 ENTER LONGEST JOINT SPACING (IN FEET) [JS-L]
I>25
 ENTER SHORTEST JOINT SPACING [JS-S]
I>25
 ENTER AVERAGE ANNUAL TEMPERATURE (F) [TEMP]
I>42
 ENTER FREEZING INDX (DEGREE DAYS BELOW 32F) [FI]
I>600
 ENTER % OF TOTAL SLABS CONTAINING LARGE PATCHES (OVER 5 SQ FT) [PATCH]
 OR    % AREA OF TOTAL AREA PATCHED IF OVERLAID WITH ASPHALT
I>1
 ENTER MODULUS OF RUPTURE [MR]
I>650
 ENTER INTERIOR STRESS [STRESS]
I>375
 DOES ASPHALT OVERLAY EXIST? (Y/N)
I>N

 ACCEPT,CHANGE,DISPLAY? (A/C/D)
I>A
 ENTER PREDICTION AGES SINCE LAST CONST/OVERLAY, SEPARATED BY COMMAS
I>0,5,10,15,20
```

Figure 25. Input for Concrete Pavement -- Do Nothing Alternative

```
TEST2

     0.0 % OF TOTAL SLABS REPLACED
    25.0 LONGEST JOINT SPACING (IN FEET)
    25.0 SHORTEST JOINT SPACING
    42.0 AVERAGE ANNUAL TEMPERATURE (F)
   600.0 FREEZING INDX (DEGREE DAYS BELOW 32F)
     1.0 % OF TOTAL SLABS CONTAINING LARGE PATCHES (OVER 5 FT)
         OR % OF TOTAL AREA PATCHED IF OVERLAID WITH ASPHALT
   650.0 MODULUS OF RUPTURE
   375.0 INTERIOR STRESS
      -- NO ASPHALT OVERLAY


 AGE SINCE LAST CONST/OVERLAY              PCI
 ----------------------------              ---
              0.0                         100.0
              5.0                          90.2
             10.0                          80.3
             15.0                          70.5
             20.0                          60.7
```

Figure 26. Output for Concrete Pavement -- Do Nothing Alternative

```
 DO YOU WISH TO DETERMINE THE CONSEQUENCE OF
 AC OVERLAY(AC), PCC OVERLAY(PCC), SLAB REPLACEMENT(SR)
 CHANGE IN AIRCRAFT(A), OR NONE(N)?  (AC/PCC/SR/A/N)
I>SR
 ENTER AGES SINCE LAST CONST/OVERLAY TO REPLACE SLABS
 FOLLOWED BY PERCENT SLABS TO BE REPLACED
 ONE PAIR PER LINE. ("END") TO END
I>20,5
I>END
 ENTER PREDICTION AGES SINCE LAST CONST/OVERLAY, SEPARATED BY COMMAS
I>0,5,10,15,20,25,30
```

Figure 27. Input for Slab Replacement

```
TEST2

     0.0 % OF TOTAL SLABS REPLACED
    25.0 LONGEST JOINT SPACING (IN FEET)
    25.0 SHORTEST JOINT SPACING
    42.0 AVERAGE ANNUAL TEMPERATURE (F)
   600.0 FREEZING INDX (DEGREE DAYS BELOW 32F)
     1.0 % OF TOTAL SLABS CONTAINING LARGE PATCHES (OVER 5 FT)
         OR % OF TOTAL AREA PATCHED IF OVERLAID WITH ASPHALT
   650.0 MODULUS OF RUPTURE
   375.0 INTERIOR STRESS
      -- NO ASPHALT OVERLAY

     5.0 PERCENT SLABS TO BE REPLACED AT AGE        20.0


AGE SINCE LAST CONST/OVERLAY            PCI
----------------------------            ---
            0.0                        100.0
            5.0                         90.2
           10.0                         80.3
           15.0                         70.5
           20.0                         63.1
           25.0                         53.9
           30.0                         44.6
```

Figure 28. Effect of Slab Replacement

SECTION VII

COST COMPUTATION MODULE (COSCOM)

Several types of costs are used by a decision-maker in evaluating the best M&R alternative for a given pavement feature. These costs can include the following:

1. Initial cost of the alternative (first-year cost).

2. Present value of the alternative (discounted cost of the alternative in present dollars, using interest and inflation rates).

3. Equivalent uniform annual cost (EUAC) of the alternative (present value cost converted to an annuity).

4. EUAC per square yard of pavement.

All of these costs are calculated in the cost computation module (COSCOM). The description of COSCOM in this section will be concerned only with the costs that are associated with M&R alternatives for individual features. A block diagram of the module is shown in Figure 29.

1. INITIAL COST

The initial cost is the present-year cost of the alternative, disregarding any future costs. The value is used in the budget optimization module of APMS (see Section IX). The initial cost is represented by the symbol C_I in this report.

2. PRESENT VALUE COSTS

In economic analyses, the effects of interest and inflation rates are commonly taken into account. The inflation rate is used to adjust the future cost of an M&R alternative according to the following formula:

$$C_{mt} = C_m(1 + r)^t \tag{6}$$

where: C_m = the cost of the M&R alternative in present-day dollars
r = the annual rate of inflation in decimals
t = the time in the future in years
C_{mt} = the cost of the M&R alternative t years in the future.

So that all dollar figures are considered on an equivalent basis, it is common practice to reduce all future costs to their present value by applying an interest rate discount, i. The present value of the future cost C_{mt} is:

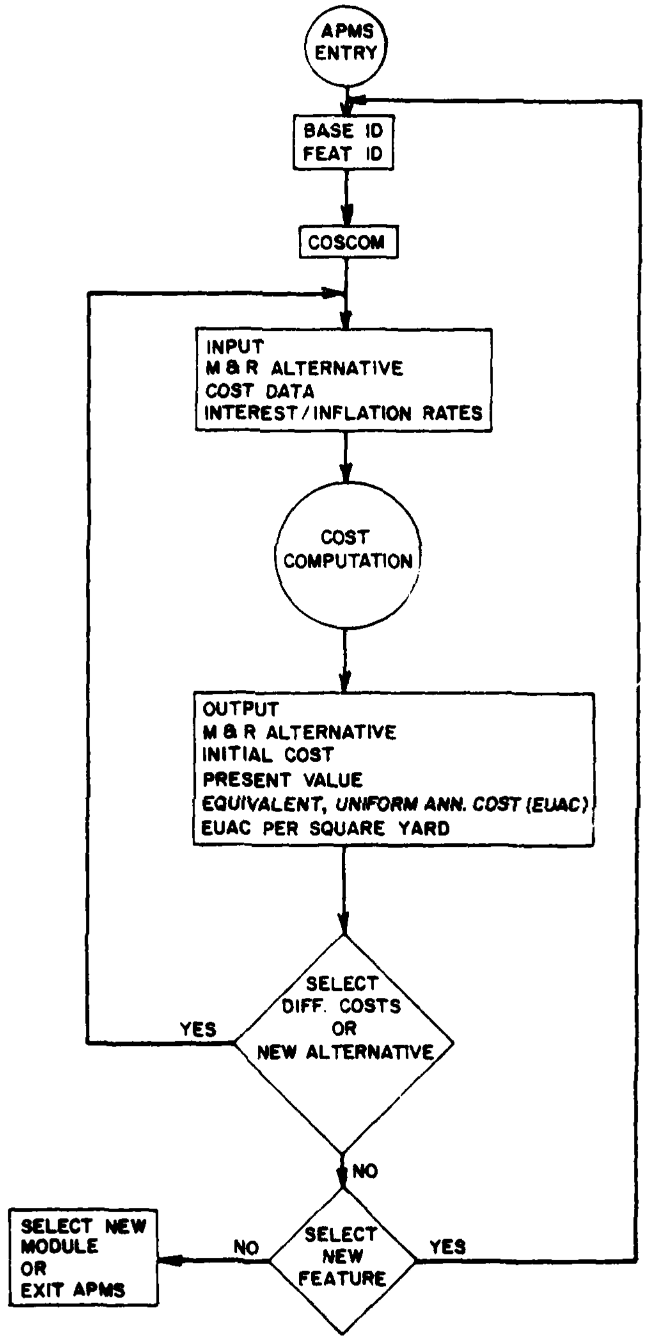

Figure 29. Block Diagram of COSCOM Module

$$PV = \frac{C_{mt}}{(1 + i)^t} \qquad (7)$$

where: PV = the present value; that is, the amount of money that would have to be placed in an interest-bearing account now to be C_{mt} in t years
i = the annual rate of interest in decimals.

Combining Equations (6) and (7), the formula for present value becomes:

$$PV = C_m\left(\frac{1 + r}{1 + i}\right)^t \qquad (8)$$

This formula allows the user to input data in present-day dollars.

In most cases, an M&R alternative consists of a series of M&R activities with associated costs. The present value of a series of M&R costs is found by adding the initial cost, C_I, to the present value of all future costs adjusted for inflation and interest rates. The present value of this series of costs is:

$$PV = C_I + \sum_{t=1}^{N} \frac{C_{mt}}{(1 + i)^t} \qquad (9)$$

or

$$PV = C_I + \sum_{t=1}^{N} C_m\left(\frac{1 + r}{1 + i}\right)^t \qquad (10)$$

where: N = the number of years in the analysis period.

The present-value analysis is a convenient tool in the decision-making process because it allows choices to be made in terms of present-day dollars. The user can avoid comparing present-day dollars with dollars several years in the future.

3. EQUIVALENT UNIFORM ANNUAL COST

The EUAC is calculated as follows: the annual payments over the analysis period are individually discounted and added; this sum is the present value (PV). The EUAC is necessary for comparing M&R alternatives with different

lives. To compute the EUAC, the present value is multiplied by the capital recovery factor (CRF):

$$EUAC = CRF \times PV \tag{11}$$

where

$$CRF = \frac{i\,(1 + i)^N}{(1 + i)^N - 1} \tag{12}$$

4. EQUIVALENT UNIFORM ANNUAL COST PER SQUARE YARD

The EUAC is divided by the surface area of the feature to which it applies so that the result may be used in the budget optimization module (BUDOPT) (Section IX) as dollars per square yard.

5. DATA INPUT

Each M&R alternative being considered for a given feature requires a different sequence of M&R activities. Two types of cost inputs to COSCOM account for these activities.

a. Anticipated One-Time Costs

Anticipated one-time costs is a listing of the initial and future anticipated M&R activities. Each activity, its estimated costs, and its timing are input. Table 16 provides an example: the initial cost, calculated by adding all costs in 1980, is $644,897.

TABLE 16. EXAMPLE COST INPUT: ANTICIPATED ONE-TIME COSTS

M&R Activity Description	Year	Cost, Dollars
Seal cracks	1980	51,053
Patch alligator cracking	1980	5,361
Apply tack coat	1980	11,333
Overlay with 2-inch asphalt-concrete	1980	543,150
Apply rejuvenator construction coat	1980	34,000
Seal cracks	1982	10,000
Seal cracks	1984	20,000

b. Anticipated Periodic Costs

An M&R alternative may be composed of M&R activities to be performed at regular intervals over the life of the alternative. A periodic cost may be started at any time in the future and last the life of the alternative.

An example of a periodic cost input is shown in Table 17. Crack sealing, costing $30,000 (based on 1980 estimates), is planned every 2 years--beginning in 1986 and lasting until the end of the life of the M&R alternative. Since the alternative started in 1980 and is to last 20 years, the module assumes that crack sealing will be done in 1986, 1988, 1990, 1992, 1994, 1996, and 1998. Note that no crack sealing is scheduled for the year 2000 because that is the end of the life of the alternative.

6. EXAMPLE OF INPUT AND OUTPUT

The inputs to the COSCOM module for a given M&R alternative include the life of the alternative and the cost data for years when work is planned. The module assumes no cost for the years not input. Periodic activities within an alternative are input by entering, after the cost data, the number of years between activities. If no number is input, the activity is assumed to be a one-time future cost. Figure 30 is an example of input to the COSCOM module based on data from Tables 16 and 17. The user input follows the I> symbol. The resulting output for this example is shown in Figure 31. The user may also request a summary of the output, as shown in Figure 32.

TABLE 17. EXAMPLE COST INPUT: PERIODIC COST

M&R Activity Description	Year	Cost, Dollars	Time, Spacing
Seal cracks	1986	30,000	2 years
Apply rejuvenator	1988	45,333	8 years

```
COST ANALYSIS SELECTED:                    (CR TO EXIT)
FOR AMEDEE ENTER:
1. M&R ALTERNATIVE DESC.(25 CHAR):
I>OVERLAY
2. YEAR TO START ANALYSIS:
I>1980
3. LIFE OF ALTERNATIVE(YRS):
I>20
4. INTEREST RATE(%):
I>10
5. INFLATION RATE(%):
I>12
M&R ACTIVITY #  1 DESC:   (CR TO EXIT)
I>SEAL CRACKS
YEAR  COST  TIME-SPACING
I>1980 51053
I>
M&R ACTIVITY #  2 DESC:   (CR TO EXIT)
I>PATCH ALLIGATOR CRK
YEAR  COST  TIME-SPACING
I>1980 5361
I>
M&R ACTIVITY #  3 DESC:   (CR TO EXIT)
I>APPLY TACK COAT
YEAR  COST  TIME-SPACING
I>1980 11333
I>
M&R ACTIVITY #  4 DESC:   (CR TO EXIT)
I>OVERLAY,2 IN. AC
YEAR  COST  TIME-SPACING
I>1980 543150
I>
M&R ACTIVITY #  5 DESC:   (CR TO EXIT)
I>APPLY LIGHT REJUV
YEAR  COST  TIME-SPACING
I>1980 34000
I>
M&R ACTIVITY #  6 DESC:   (CR TO EXIT)
I>SEAL CRACKS
YEAR  COST  TIME-SPACING
I>1982 10000
I>1984 20000
I>1986 30000 2
I>
M&R ACTIVITY #  9 DESC:   (CR TO EXIT)
I>APPLY REJUV
YEAR  COST  TIME-SPACING
I>1988 45333 8
I>
```

Figure 30. Input to COSCOM Module

```
DATE:=   30 NOV 81       PROJECTED COST ANALYSIS            (DETAIL)

BASEID:= SIERRA                                   FEATID:= AMEDEE
BASENM:= SIERRA ARMY DEPOT                        FEATNM:= AMEDEE AIR STRIP

ALTERNATIVE:= OVERLAY                             FEATURE AREA(S.Y.):= 113333.0
LIFE OF ALTERNATIVE:= 20 INTEREST RATE:= 10.0   INFLATION RATE:=  12.0

M&R ACTIVITY              YEAR          COST(S)       PRESENT VALUE($)

SEAL CRACKS               1980         51053.00         51053.00
PATCH ALLIGATOR CRK       1980          5361.00          5361.00
APPLY TACK COAT           1980         11333.00         11333.00
OVERLAY,2 IN. AC          1980        543150.00        543150.00
APPLY LIGHT REJUV         1980         34000.00         34000.00
                        TOTAL:=       644897.00        644897.00

SEAL CRACKS               1982         10000.00         10366.94
SEAL CRACKS               1984         20000.00         21494.70
SEAL CRACKS               1986         30000.00         33425.14

SEAL CRACKS               1988         30000.00         34651.65
APPLY REJUV               1988         45333.00         52362.11
                        TOTAL:=        75333.00         87013.77

SEAL CRACKS               1990         30000.00         35923.17
SEAL CRACKS               1992         30000.00         37241.34
SEAL CRACKS               1994         30000.00         38607.88

SEAL CRACKS               1996         30000.00         40024.57
APPLY REJUV               1996         45333.00         60481.12
                        TOTAL:=        75333.00        100505.69

SEAL CRACKS               1998         30000.00         41493.24

INITIAL COST($):=                             644897.00
PRESENT VALUE($):=                           1050968.87
EQUIVALENT UNIFORM ANNUAL COST($):=           123446.41
EUAC PER SQ. YD. ($):=                             1.09
            ------------ END OF REPORT -----------
```

Figure 31. Output From COSCOM Module

```
DATE:=  30 NOV 81       PROJECTED COST ANALYSIS           (SUMMARY)

BASEID:= SIERRA                                  FEATID:= AMEDEE
BASENM:= SIERRA ARMY DEPOT                       FEATNM:= AMEDEE AIR STRIP

ALTERNATIVE:= OVERLAY                            FEATURE AREA(S.Y.):= 113333.0
LIFE OF ALTERNATIVE:= 20 INTEREST RATE:= 10.0   INFLATION RATE:=  12.0


INITIAL COST($):=                                644897.00
PRESENT VALUE($):=                              1050968.87
EQUIVALENT UNIFORM ANNUAL COST($):=              123446.41
EUAC PER SQ. YD. ($):=                                1.09
                  ------------ END OF REPORT -----------
SELECT:(A-F)     (H=HELP)
I>F
 SELECT(A-J):=          H=HELP
I>J
 END APMS SYSTEM
```

Figure 32. Output Summary

SECTION VIII

BENEFITS COMPUTATION MODULE (BENCOM)

The calculation of relative weighted benefits for a given pavement feature and one or two M&R alternatives could be done manually. However, if there are many features, pavement types, and alternatives, the computational effort increases dramatically. Therefore, the benefits computation module (BENCOM) has been developed to calculate benefits.

This section defines benefits as they are used in BENCOM and illustrates how they are calculated. The benefits of keeping a pavement feature in service will eventually be computed in terms of dollars, but economic studies of these benefits have not yet been made. As an interim measure, benefits are defined with nonmonetary criteria which will reflect the patterns of benefit that decision-makers normally expect.

These criteria are: (1) maintenance of a high pavement condition rating, (2) type of facility, and (3) level of PCI. Decision-makers tend to prefer an M&R alternative which maintains a high pavement-condition rating. In addition, the type of facility is often important; for example, if funding is limited, a primary runway -- rather than a secondary apron -- is repaired. The level of rating that a decision-maker is willing to pay for depends on how high the existing rating is. It would be preferable to pay extra money to raise the PCI from 50 to 55, rather than spending the same amount to raise it from 95 to 100 -- at this level, the pavement is already in acceptable condition. The relative value of raising the PCI is called a utility, which is explained in DEFINITION OF TERMS, below.

The three nonmonetary criteria have been included in the BENCOM module to compute the benefit derived from a given M&R alternative.

1. DEFINITION OF TERMS

a. Benefits

Although benefits are usually calculated in terms of dollars, it is also possible, and even desirable occasionally, to compute benefits in nonmonetary units. Such is the case with the current BENCOM. Benefits are defined as the product of performance area (the area under the PCI time curve), utility, and level of service factors.

b. Performance Area

The performance area is the area under the PCI time curve bounded by the minimum PCI value. A graph of a PCI versus time curve is shown in Figure 33. The cross-hatched portion indicates the performance area. The larger the performance area, the more reliable the pavement. That is, a reliable pavement will hold a high PCI rating for an extended time.

Figure 34 is a PCI time graph for three M&R alternatives. As shown, alternatives 1 and 2 have the same performance areas. Alternative 2, lasting

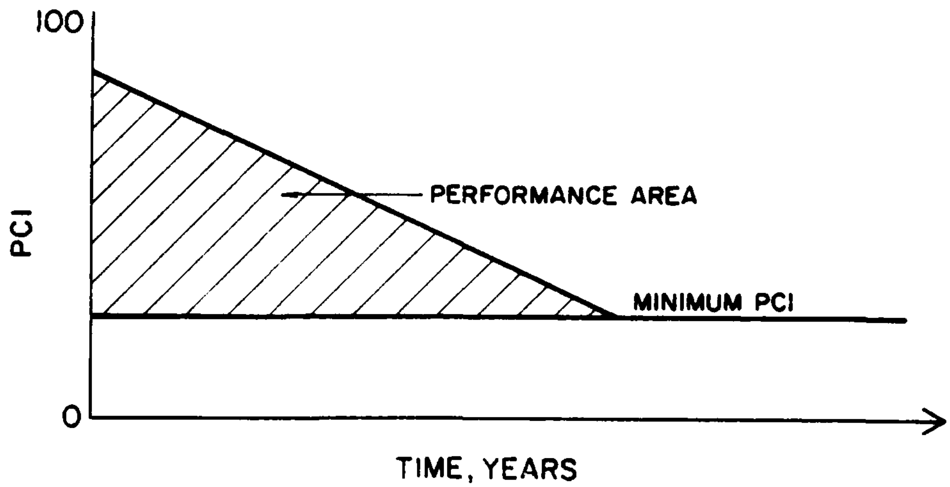

Figure 33. Illustration of Performance Area

slightly longer, maintains a lower rating over the life of the alternative. Clearly, alternative 3 produces the greatest performance area and maintains a high rating longer than either alternative 1 or alternative 2. If performance area were the only criterion, alternative 3 would be chosen. However, as illustrated by alternatives 1 and 2, equal performance area does not provide the same pavement condition. This area must be weighted by some value which is a function of the PCI. Such a value is called utility.

c. Utility

A utility is a subjective preference rating between 0 and 1, the higher number indicating a higher preference. The concept of utility was used in defining benefit because experienced engineers usually are not greatly concerned about the PCI of a primary runway pavement if it is above 90. Similarly, on less important features the zone of indifference is reached at lower values of PCI.

On the other hand, the engineer is greatly concerned about raising the PCI value from 35 to 45 or higher. With a preference scale of 0 to 1, utility curves were developed for six types of features (primary and secondary runways, taxiways, and aprons). These curves were constructed based on the average response of a panel of major command engineers. [See Volume IV of Development of a Pavement Maintenance Management System (Reference 4) for complete details.] These curves are shown in Figures 35, 36, and 37 for runways, taxiways, and aprons, respectively.

Once the utility values have been defined, a modified PCI time graph can be developed (Figure 38). This is done by multiplying the time length Ti (at PCI level i) by the corresponding utility value U_i. This produces a reduced time length, TiU_i, which represents the perceived value of the PCI at that level (Figure 38). The weighted performance area is then calculated as the area under the utility-weighted PCI versus time, bounded by the minimum PCI value.

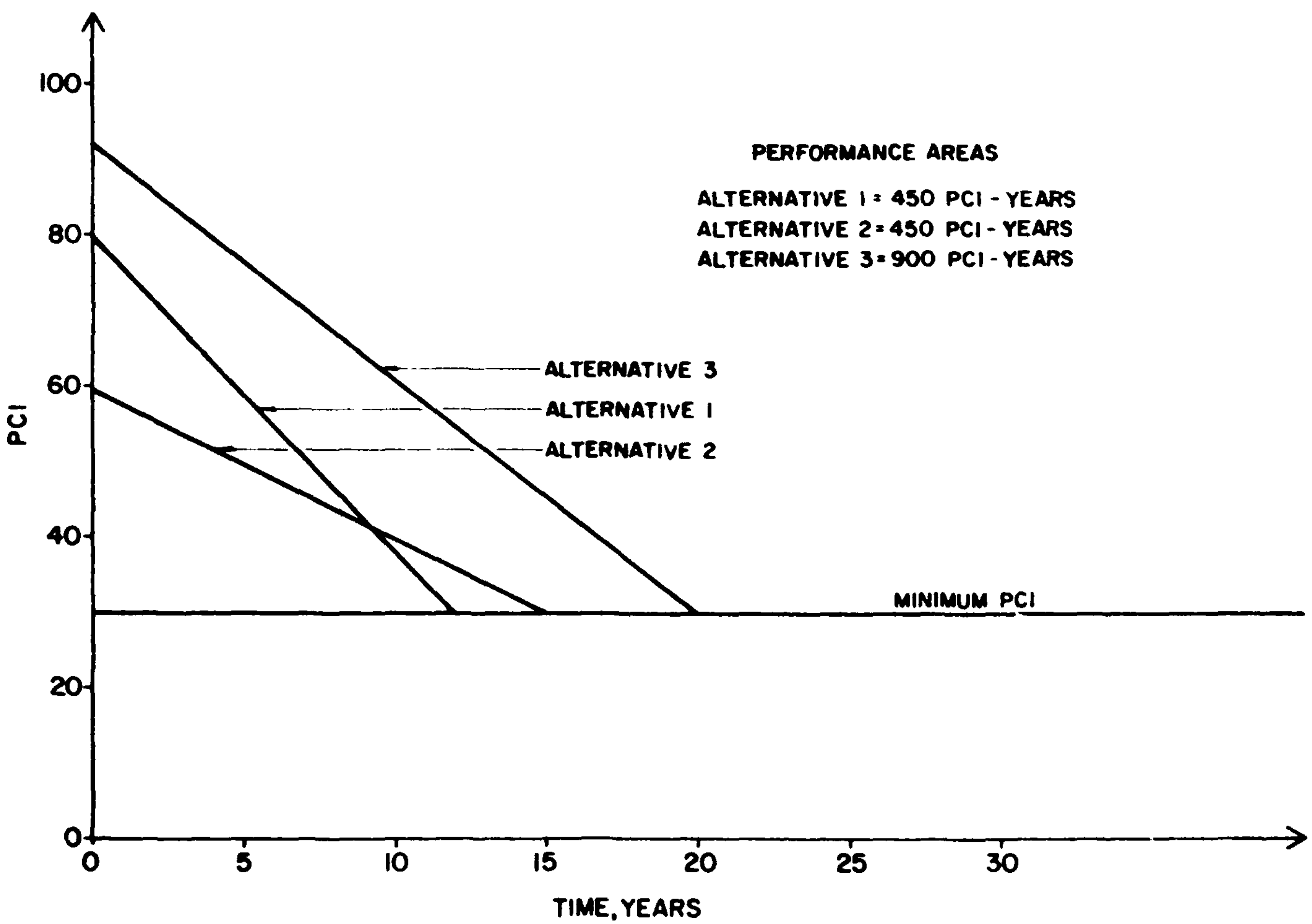

Figure 34. Comparison of Alternative and Performance Area

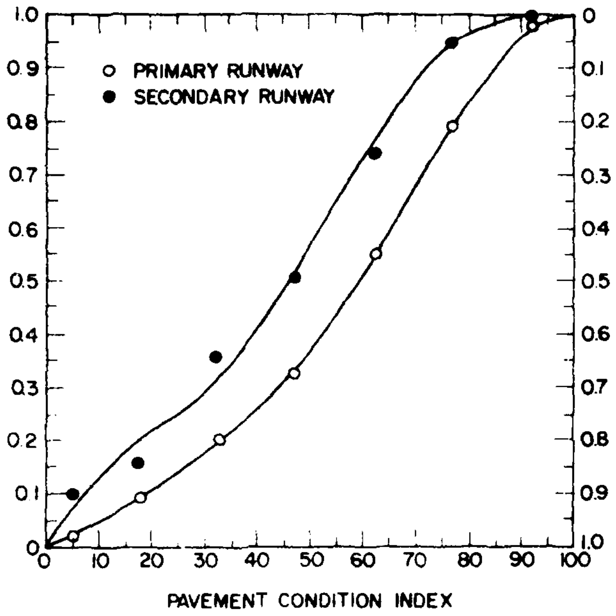

Figure 35. PCI for Runways

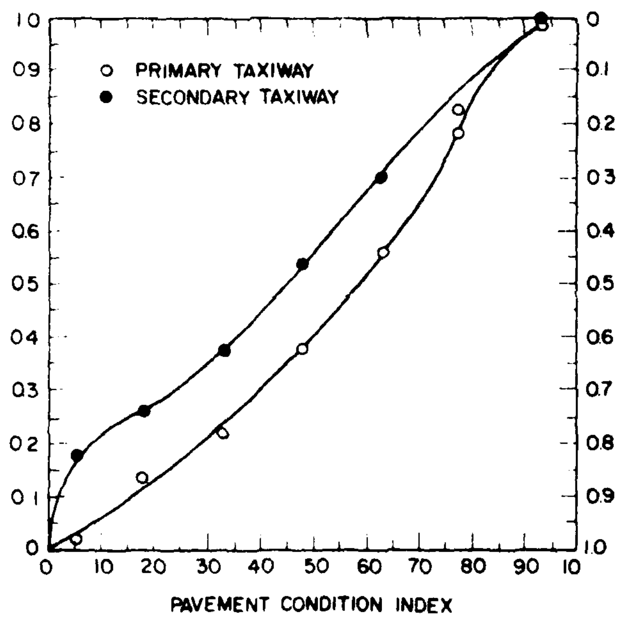

Figure 36. PCI for Taxiways

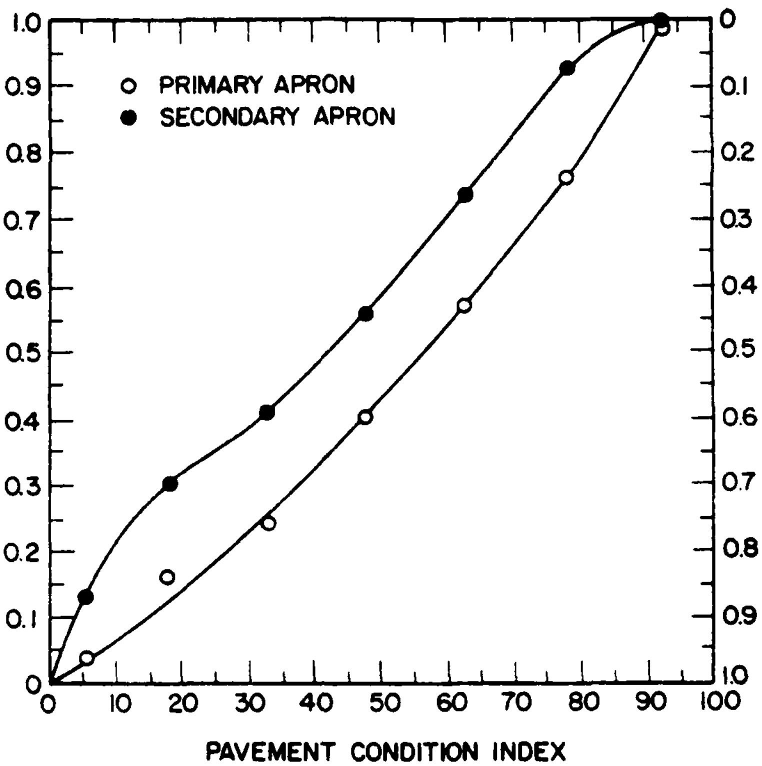

Figure 37. Level of Satisfaction and Performance Weighting Factor Versus PCI for Aprons

4. Relative Weights

The utility weights for PCI indicate the relative performance area of repairing or maintaining different types of facilities, such as runways, taxiways, and aprons. In addition, a relative weight is applied to compute benefits in order to indicate the importance of each of these facilities to the overall mission of an airfield. The relative weights were considered a necessary part of the computation of benefits because of the need to set cost allocation priorities for these three types of facilities. For example, it is possible that two features, one in a primary runway and one in a secondary apron, have the same utility-weighted performance area. If it became necessary to choose between the two, the prudent decision-maker would generally decide to allocate limited M&R funds to the runway rather than to the apron feature. Relative weights are used to rank the three types of facilities so that a consistent method of computing benefits, and thus of allocating scarce funds, can be adopted. The relative weights that are input to BENCOM are based on a scale of 0 to 1. An example of relative weights is given in Table 18.

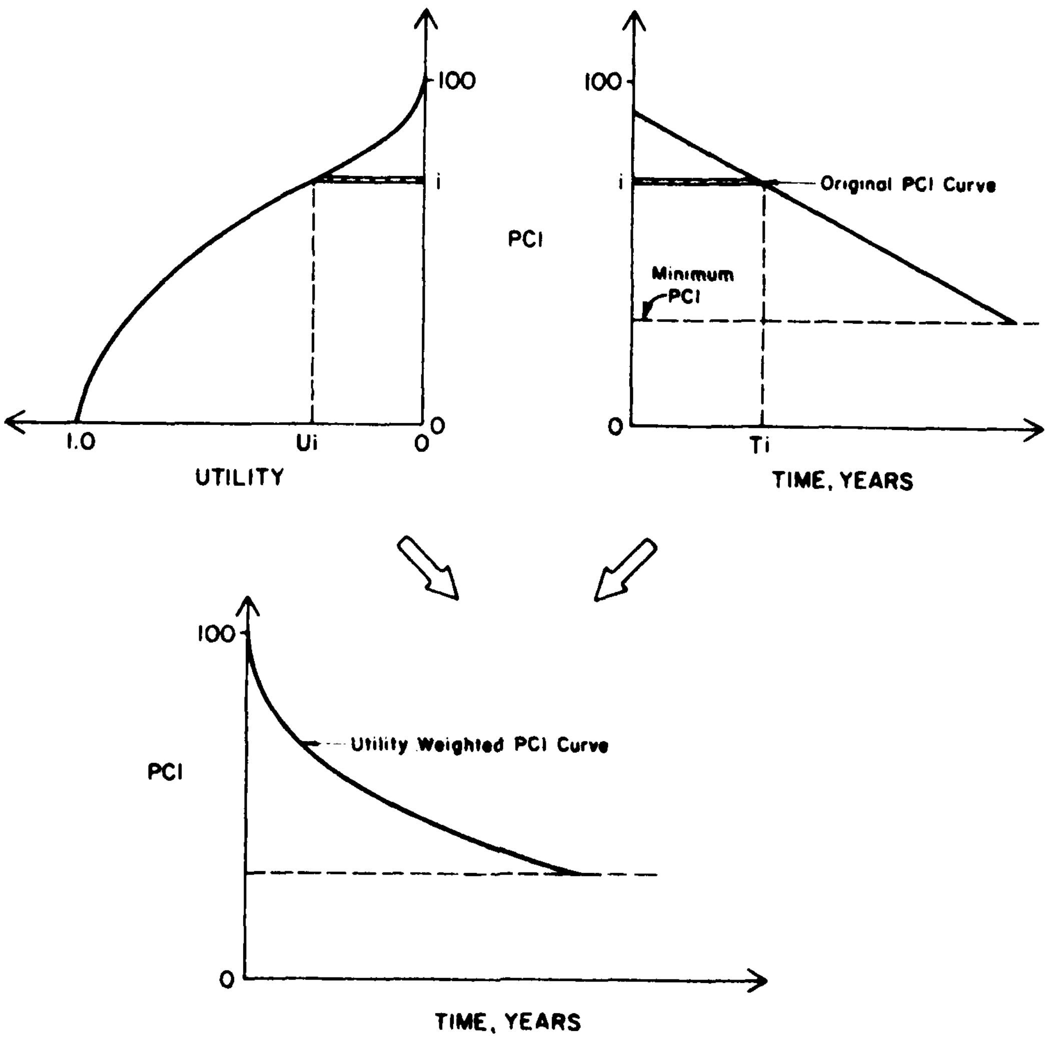

Figure 38. Utility Weighting of the PCI Versus Time Curve

TABLE 18. EXAMPLE RELATIVE WEIGHTS

Facility	Relative Weights
Primary runway	1.00
Secondary runway	0.85
Primary taxiway	0.90
Secondary taxiway	0.70
Primary apron	0.85
Secondary apron	0.50

These weights indicate each type of facility's relative importance as perceived by the decision-maker. He/she has the option to set the same weight on all types of facilities and to let the benefits be calculated based on performance area and utility alone.

e. Minimum PCI Rating

The computed benefit depends as much on the minimum value of the PCI as it does on the actual PCI. Therefore, care must be taken in determining this minimum value, which should be established at one of two PCI levels: (1) where no additional benefit is derived from keeping the feature in operation, or (2) where some type of major or overall M&R must be done before the PCI drops off even more. The two points may be reached simultaneously. Sample values of minimum PCIs are listed in Table 19.

TABLE 19. EXAMPLE MINIMUM PCI VALUES

Facility	Minimum PCI
Primary runway	20
Secondary runway	15
Primary taxiway	20
Secondary taxiway	15
Primary apron	15
Secondary apron	10

2. BENEFITS FOR THE DO NOTHING ALTERNATIVE

Certain benefits can be derived from doing nothing to a feature if the current level of PCI is above the minimum. The performance area of the do nothing alternative is shown as the shaded area between the PCI curve and the minimum PCI in Figure 39. The performance area that is derived from applying an M&R alternative is not the area between the PCI versus time curve and the minimum PCI. Instead, it is the *difference* between the total area and the area beneath the do nothing line. That difference is the shaded area shown in Figure 40. In general, the benefits are calculated differently depending on whether the current value of the PCI is above or below the minimum PCI:

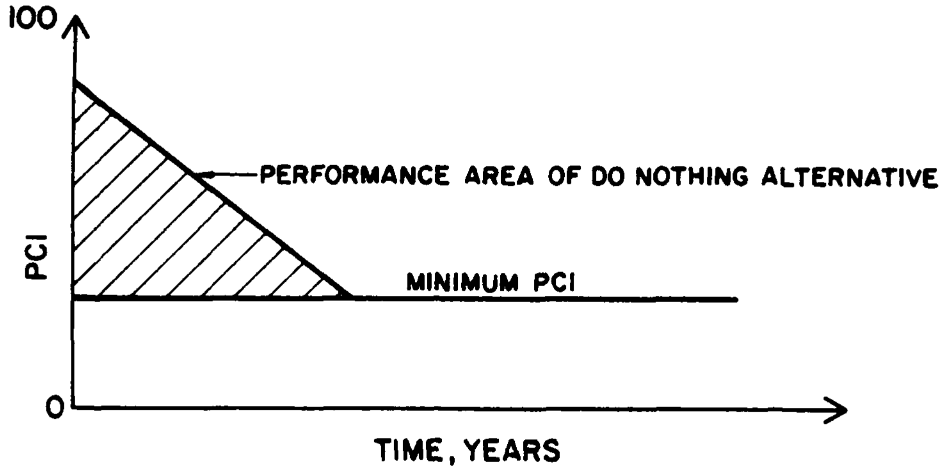

Figure 39. Performance Area Under Do Nothing PCI Time Curve

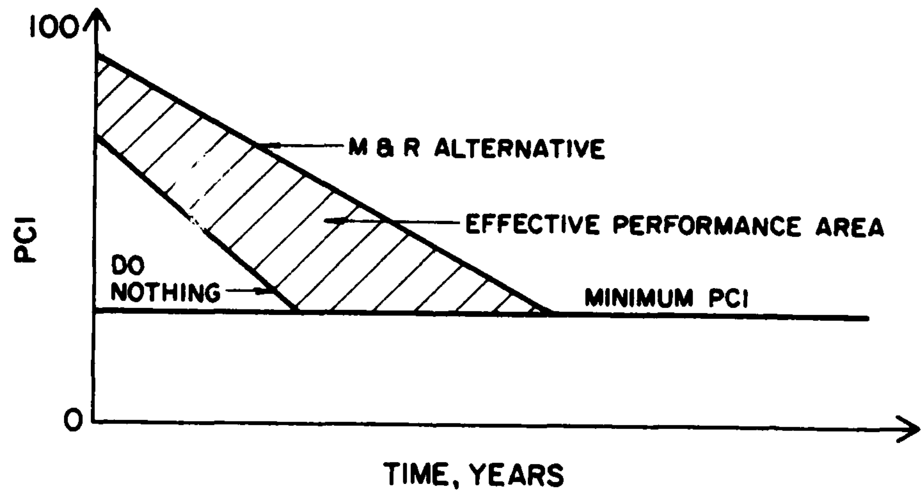

Figure 40. Performance Area Gained by Applying an M&R Alternative

a. Current PCI at or below minimum PCI -- benefits are the total area between the utility-weighted PCI versus time curve for a new M&R alternative and the current PCI value.

b. Current PCI above minimum PCI -- benefits are the total area above the minimum PCI line and the do nothing PCI versus time curve, and below the utility-weighted PCI versus time curve for a new M&R alternative.

3. RELATIVE UTILITY-WEIGHTED BENEFITS

If there is no desire to use BUDOPT, the total benefit for a feature, or the relative utility-weighted benefit, may be regarded as the product of:

$$\text{(Relative Weight)} \times \text{(Utility)} \times \text{(Area Under PCI-Time Curve)} \qquad (13)$$

This benefit may be calculated for each M&R alternative considered for each feature. A graph of the relative weighted benefit versus the total required budget can be drawn as shown in Figure 41. A decision-maker then can choose the M&R alternative which produces the maximum benefit within the budget that has been allocated for a feature. The cost and benefit figures illustrated in Figure 41 are given in Table 20.

If the budget is strictly limited to the lower figure ($48,000), then the M&R alternative should be selected. This would produce the maximum benefit within the restricted budget range. M&R alternative 1 is the do nothing alternative; it is listed at zero in Table 20 since, by definition, benefit is the increase in benefit over the do nothing alternative.

There is often some flexibility in setting the allowable budget for any specific feature because that feature is usually a part of an overall M&R program. If the budget could be relaxed about $6000 (increased to $54,000) in the case illustrated in Figure 41, the benefit could be doubled if M&R alternative 5 were selected. Relaxing the budget restrictions on one project is usually done by taking funds away from a lower priority project. As long as the number of features -- and the possible alternatives on each -- remain fairly small, it is usually easy to select the best M&R alternatives for each feature by modifying budget limitations to maximize the benefit. However, as the number of features and alternatives increases, a computerized method of selecting the best set of alternatives becomes advantageous (Section IX).

4. ANNUAL BENEFITS

To have a consistent basis for comparing costs and benefits in BUDOPT, costs must be entered and benefits must be computed on an annual basis. This calculation may be done in two ways: one is the linear method and the other is the capitalized benefit method. The method selected will depend on how the decision-maker views benefits. Since benefits are measured in nonmonetary units, some decision-makers may consider them independent of interest and inflation rates. If this is the case, the linear method may be used to compute annual benefits:

TABLE 20. BENEFIT AND COST VALUE USED IN FIGURE 41

M&R Alternative Number	Benefit	Relative Utility Weighted Cost, Dollars	Budget, Dollars
1	0	0	
2	300	13,000	
3	400	23,000	
4	320	42,000	48,000 (Lower budget limit)
5	800	54,000	60,000 (Upper budget limit)
6	980	78,000	

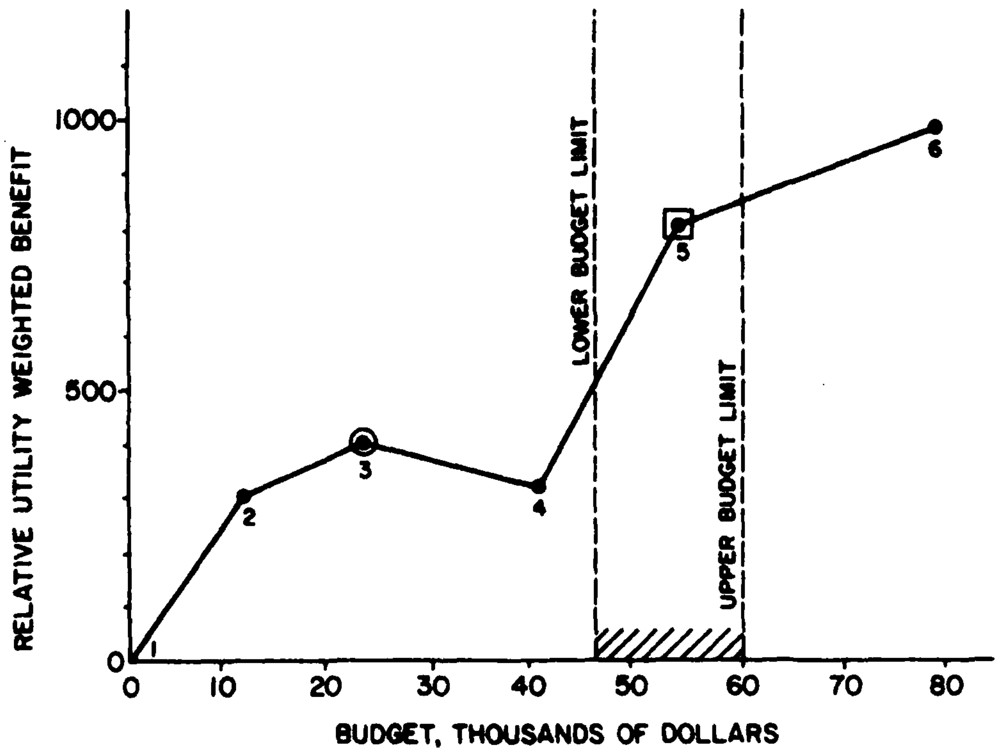

Figure 41. Graph of Benefit Versus Budget for Six M&R Alternatives

$$\text{Annual Benefits} = \frac{\text{Relative Utility-Weighted Benefits}}{\text{Time to Reach Minimum PCI}} \qquad (14)$$

On the other hand, if benefits are considered roughly proportional to the dollar value of keeping a feature in service, then the capitalized benefit method may be used and the annual benefits approximated with the CRF.

$$\text{Annual Benefits} = \text{Relative Utility-Weighted Benefits} \times \text{CRF} \qquad (15)$$

where: $\text{CRF} = \dfrac{i(1 + i)^T}{(1 + i)^T - 1}$

T = time to reach minimum PCI

i = interest rate.

The BENCOM module now uses the linear method.

5. SYSTEM DESCRIPTION

Relative weighted benefits were defined in Equation 13. The relative weights, utility curves, and minimum PCI values have default values in the BENCOM module. These values may be changed by the user temporarily or permanently. The values used for the relative weights and minimum PCI are listed in Tables 18 and 19, respectively. The default values for the utility curves are shown in Table 21.

The calculation of performance area requires a PCI time curve. Since the present prediction models are linear, two points on the curve are input to the BENCOM module and the line is constructed internally. (Before the BENCOM module can be run, the CONLOC or CONOMR module must be used to obtain a PCI prediction.) A block diagram of the BENCOM module is shown in Figure 42.

6. EXAMPLE PROBLEM

For this example, consider a pavement section with the factors shown in Table 22. The user inputs these values as shown in Figure 43; the user input follows the I> symbol. The output from the module is shown in Figure 44.

TABLE 21. UTILITY VALUES FOR VARIOUS PAVEMENT FEATURE TYPES

Pavement Condition Index	Feature Type: Primary Runway	Secondary Runway	Primary Taxiway	Secondary Taxiway	Primary Apron	Secondary Apron
100	0.0	0.0	0.0	0.0	0.0	0.0
90	0.05	0.0	0.05	0.05	0.05	0.0
80	0.16	0.05	0.16	0.12	0.20	0.05
70	0.31	0.12	0.35	0.21	0.35	0.17
60	0.50	0.28	0.48	0.33	0.45	0.30
50	0.63	0.44	0.60	0.45	0.57	0.42
40	0.74	0.58	0.70	0.55	0.66	0.52
30	0.82	0.70	0.78	0.65	0.75	0.61
20	0.90	0.78	0.86	0.74	0.86	0.68
10	0.95	0.87	0.94	0.78	0.94	0.78
0	1.0	1.0	1.0	1.0	1.0	1.0

TABLE 22. PAVEMENT FACTORS FOR BENCOM EXAMPLE

Feature type: primary runway
M&R alternative: 3-inch overlay
Minimum PCI = 30 (default value)
Current PCI = 55
Project PCI for do nothing alternative = 45 in 3 years
Project PCI after repair = 100
Project PCI after repair = 80 in 4 years
Relative weights: utility curves use default values

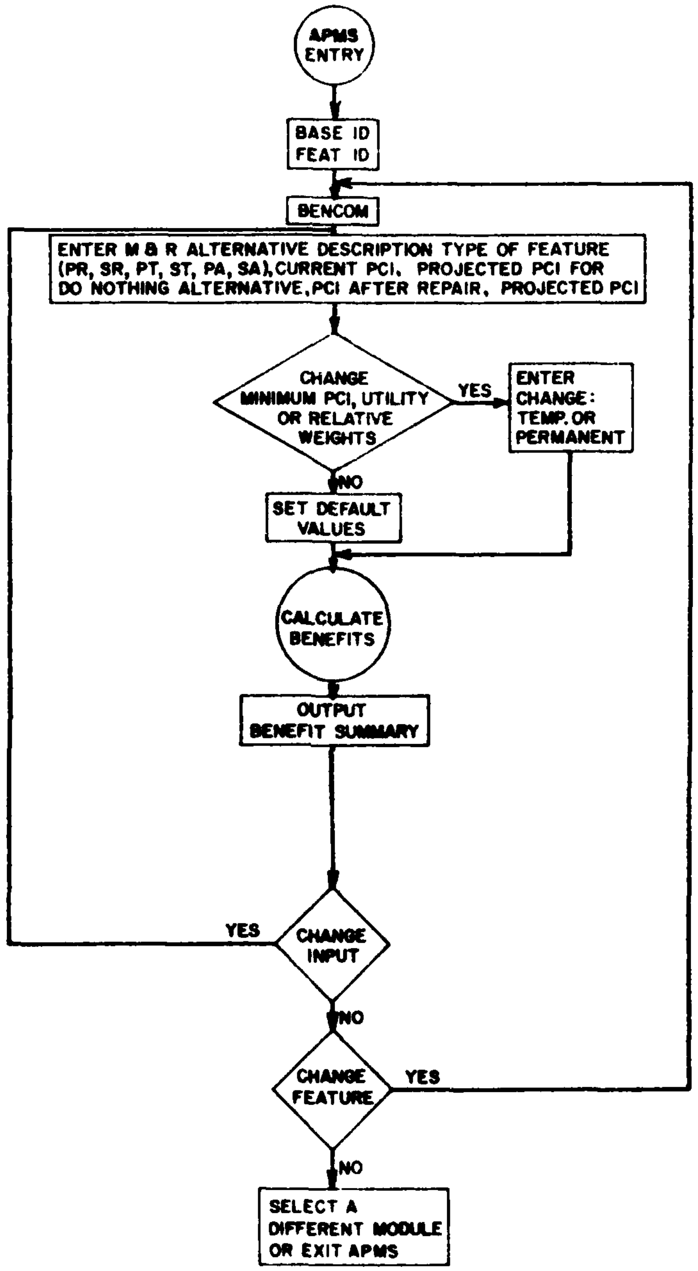

Figure 42. Block Diagram of BENCOM Module

```
BENEFIT ANALYSIS:
SELECTED: PRIMARY RUNWAY       MINPCI:= 30     RELWGT:= 1.00
ENTER PRESENT PCI:=
I>55
ENTER PREDICTED PCI FOR (DO NOTHING) ALTERNATIVE AT ANY TIME:=
I>45
ENTER TIME IN YEARS FOR (DO NOTHING ALTERNATIVE) FROM PRESENT:=
I>3
ENTER PCI AFTER REPAIR:=
I>100
ENTER PREDICTED PCI AFTER REPAIR AT ANY TIME:=
I>80
ENTER TIME IN YEARS FROM PRESENT:=
I>4
```

Figure 43. Input to BENCOM Module

```
DATE:=  24 NOV 81          BENEFIT ANALYSIS

BASEID:= STARR                                  FEATID:= TEST1
BASENM:= TEST BASE                              FEATNM:= APMS TEST

M&R ALTERNATIVE:= OVERLAY
FEATURE TYPE:= PRIMARY RUNWAY          RELATIVE WEIGHT:= 1.00
PCI:=  PRESENT:=  55    AFTER REPAIR:= 100    MINIMUM:=  30

UTILITY WEIGHTED BENEFIT:=                     203.74
RELATIVE UTILITY WEIGHTED BENEFIT:=            203.74
ANNUAL BENEFIT:=                                14.55
                ------------ END OF REPORT ------------
```

Figure 44. Output From BENCOM Module

SECTION IX

BUDGET OPTIMIZATION MODULE (BUDOPT)

To achieve the maximum benefit from limited funds available, most decision-makers try to select M&R alternatives for each feature in an M&R program. This maximization can be done by considering one feature at a time, as illustrated in the previous section (Figure 41), or all at once to maximize the overall benefits. Both of these options are available in the budget optimization module (BUDOPT). The technique used in this module has been adopted from Dr. Frank McFarland of Texas A&M University (Reference 8).

1. SCOPE

This section includes descriptions, graphs, and examples of the single feature and multiple feature optimization processes. However, this section does not provide a thorough description of the computer program and the details of the incremental benefit-cost algorithm for optimizing the use of budgeted funds in an M&R program.

2. SINGLE FEATURE OPTIMIZATION

To select the best M&R alternative for a single feature, the BUDOPT module requires the following information:

a. Upper budget limit for the feature.

b. Initial cost of each alternative.

c. Life-cycle cost of each M&R alternative. The life-cycle cost can be the present value (PV), the EUAC, or the EUAC per square yard (EUACSY) for each alternative.

d. Benefit of each M&R alternative. The benefits and costs used should be compatible. Total benefit should be used with the PV, and annual benefit with the EUAC.

The example in Table 23 illustrates the single feature optimization technique. As can be seen from this table, alternative 2 is best if the objective is to maximize the benefit/cost ratio. If the objective is to maximize the annual benefit, alternative 5 should be chosen.

3. MULTIPLE FEATURE OPTIMIZATION

To select the best M&R alternative for each feature in an M&R program, the BUDOPT must have the following data:

TABLE 23. SINGLE FEATURE OPTIMIZATION

M&R Alternative Number	Initial Cost, Dollars	EUAC, Dollars per Square Yard	Annual Benefit	Benefit/ Cost Ratio
1	0	0	0	0
2	24,000	2.10	32	15.2
3	32,000	2.80	28	10.0
4	37,000	3.20	45	14.1
5	47,000	4.10	53	12.9
6	56,000	4.90	72	14.7

Upper budget = $54,000

a. Total budget.

b. M&R alternative information for each feature. The following information must be provided for each M&R alternative:

(1) Alternative identifier.

(2) Equivalent uniform annual cost.

(3) Annual benefit.

(4) Initial cost of the alternative.

BUDOPT then uses an incremental benefit/cost algorithm to determine the best M&R alternative for each feature. The algorithm assures that the maximum benefit is achieved within the total budget available for the overall M&R program. The algorithm is discussed in more detail below.

4. THE BENEFIT/COST ALGORITHM

a. Input to the Incremental Benefit/Cost Algorithm

Table 24 is a typical set of input data for the incremental benefit/cost algorithm. The alternatives do not need to be listed in any particular order because the module will re-order them internally by increasing annual cost per square yard. Note that feature 1 includes the sample data used in the single feature optimization procedure (Table 23). This information will be used when the results of the sample problem proposed in Table 24 are assessed.

b. Calculations Within the Incremental Benefit/Cost Algorithm

The algorithm calculates the difference in costs and in benefits between successive alternatives for each feature. These differences are called incremental costs and benefits. The ratio of the two is the incremental benefit/cost ratio, which is calculated as shown in Table 25. If there is a negative incremental benefit, such as is calculated with M&R alternative 1-2, that alternative is deleted from further consideration. Therefore, alternative 1-2 has been deleted from Table 25. The negative incremental benefit can be seen graphically in Figure 45, where the line segment joining M&R alternatives 1-1 and 1-2 has a negative slope, and the benefit for 1-2 is less than that for 1-1. The slope of these line segments in Figure 45 is the incremental benefit/cost ratio. When an alternative such as 1-2 is eliminated, a new line segment is drawn between the M&R alternatives on either side of it, and a new incremental benefit/cost ratio is computed.

When one alternative exceeds the general trend of all of the others, as does M&R alternative 2-1 in Figure 46, an average incremental benefit/cost ratio is computed along the line segment joining the two highest points on the trend. In Figure 46, the two highest points are the origin and the point for alternative 2-1.

In fact, at any time there is a concave shape in the benefit/cost profile, a new average incremental benefit/cost ratio is computed, as shown in Figures 47, 48, and 49 for features 3, 4, and 5, respectively.

The next step in the computation is to rearrange the M&R alternatives in descending order of incremental benefit/cost ratios (as shown in Table 26), and to calculate cumulative initial costs, including one alternative for each feature in the total. As the computations proceed down the table, an

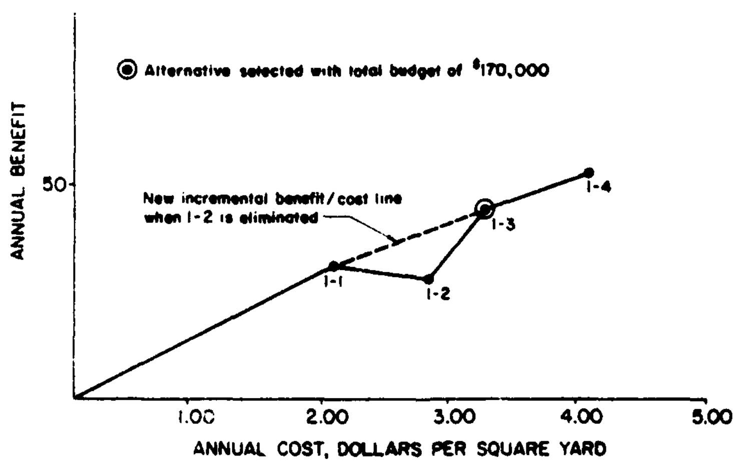

Figure 45. Graph of Annual Benefits Versus Annual Costs Per Square Yard for Feature 1

TABLE 24. TYPICAL INPUT DATA TO THE INCREMENTAL BENEFIT/COST ALGORITHM

Total available budget = $170,000
Total number of features in M&R program = 5

Feature Number	M&R Alternative Number	Annual Cost, Dollars per Square Yard	Annual Benefit	Initial Cost, dollars
1	1-1	2.10	32	24,000
1	1-2	2.80	28	32,000
1	1-3	3.20	45	37,000
1	1-4	4.10	53	47,000
2	2-1	3.50	43	43,000
2	2-2	3.40	35	43,000
2	2-3	2.80	29	35,000
3	3-1	4.20	38	46,000
3	3-2	2.70	28	29,000
3	3-3	5.70	58	62,000
4	4-1	4.00	54	41,000
4	4-2	3.60	45	37,000
4	4-3	2.90	36	30,000
5	5-1	4.60	44	48,000
5	5-2	3.40	36	36,000
5	5-3	2.50	32	26,000
5	5-4	3.80	42	40,000

TABLE 25. INTERNAL COMPUTATIONS OF THE INCREMENTAL BENEFIT/COST ALGORITHM

Feature	M&R Alternative	Annual Cost, Dollars per Square Yard	Annual Benefit	Incremental Cost, ΔC	Incremental Benefit, ΔB	Increment Benefit/ Cost Ratio, $\Delta B/\Delta C$	Average Benefit/ Cost Ratio
1	1-1	2.10	32	2.10	32	15.2	
	1-3	3.20	45	1.10	13	11.8	
	1-4	4.10	53	0.90	8	8.9	
2	2-3	2.80	29	2.80	29	10.4	
	2-2	3.40	35	0.60	6	10.0	
	2-1	3.50	43	0.10	8	80.0	12.3
3	3-2	2.70	28	2.70	28	10.4	
	3-1	4.20	38	1.50	10	6.7	
	3-3	5.70	58	1.50	20	13.3	10.0
4	4-3	2.90	36	2.90	36	12.4	
	4-2	3.60	45	0.70	9	12.9	12.5
	4-1	4.00	54	0.40	9	22.5	13.5
5	5-3	2.50	32	2.50	32	12.8	
	5-2	3.40	36	0.90	4	4.4	
	5-4	3.80	42	0.40	6	15.0	11.1
	5-1	4.60	44	0.80	2	2.5	

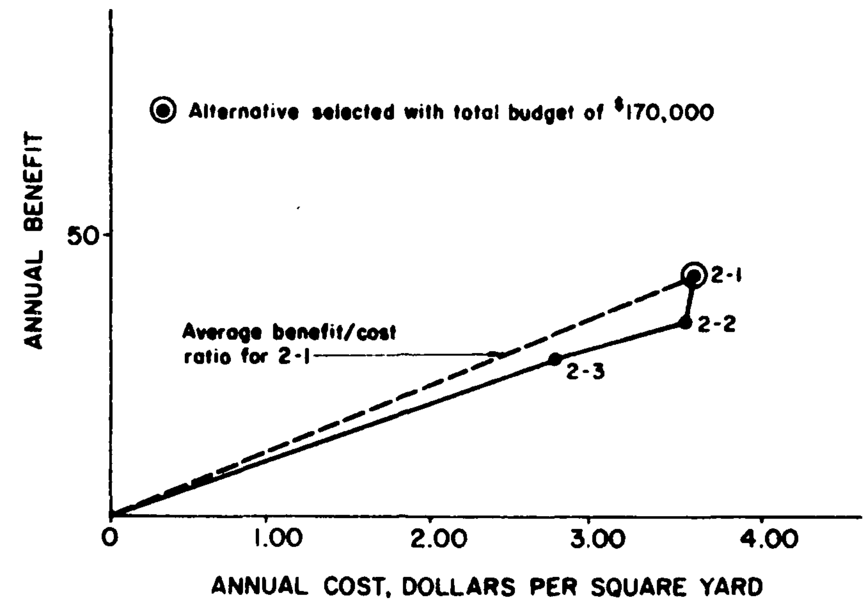

Figure 46. Graph of Annual Benefits Versus Annual Costs per Square Yard for Feature 2

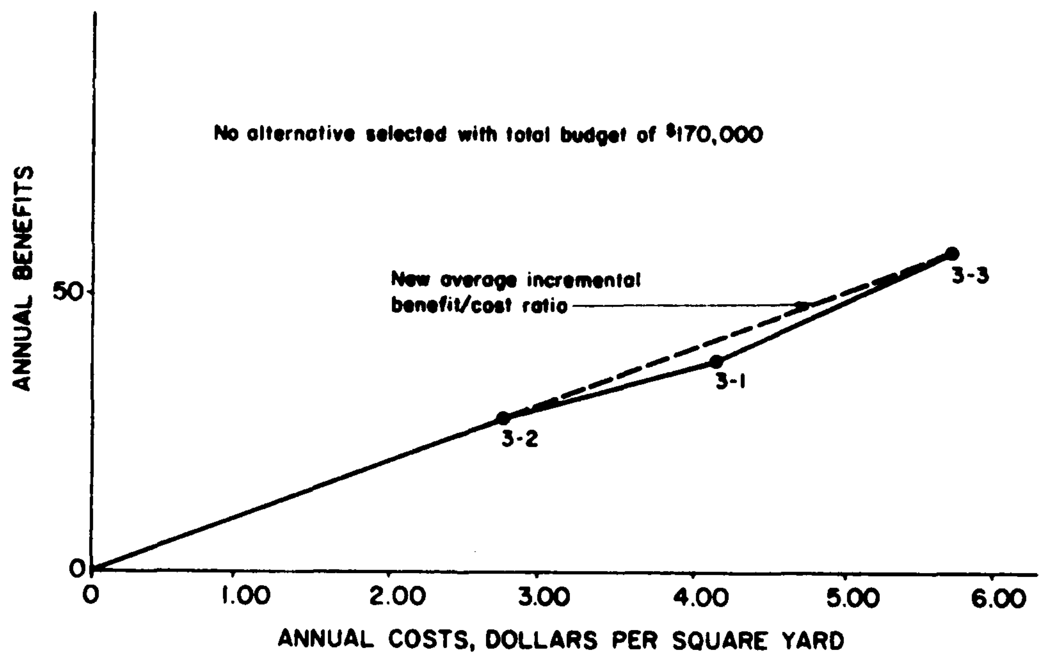

Figure 47. Graph of Annual Benefits Versus Annual Costs per Square Yard for Feature 3

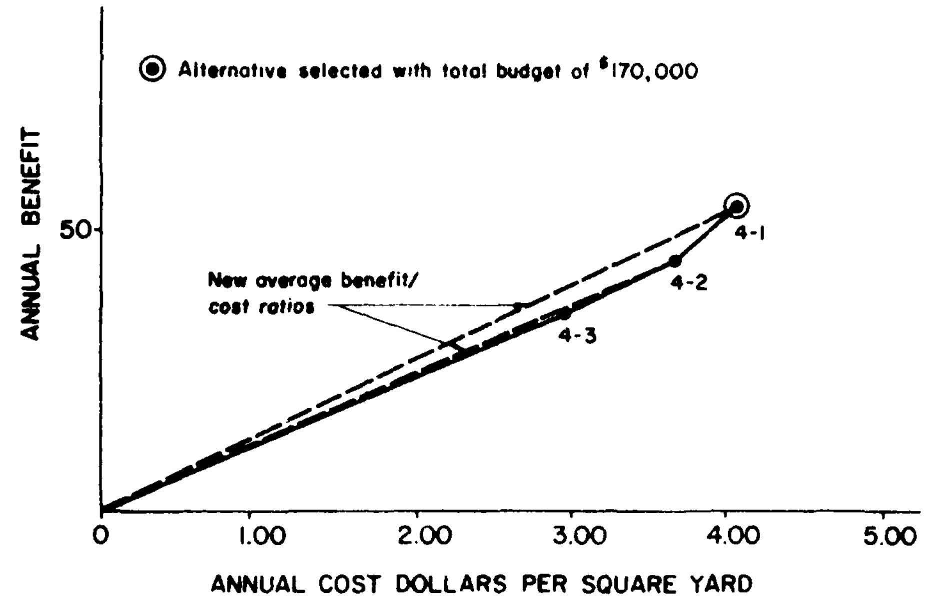

Figure 48. Graph of Annual Benefits Versus Annual Costs per Square Yard for Feature 4

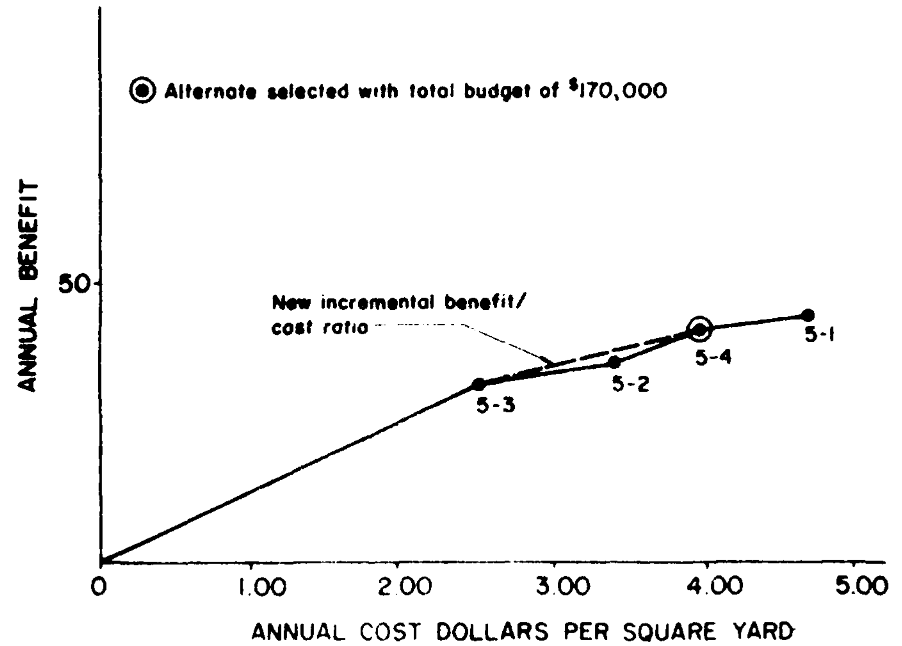

Figure 49. Graph of Annual Benefits Versus Annual Costs per Square Yard for Feature 5

TABLE 26. OUTPUT OF THE INCREMENTAL BENEFIT/COST ALGORITHM

Line	M&R Alternative	Annual Cost, Dollars per Square Yard	Annual Benefit	Incremental Benefit/ Cost Ratio	Initial Cost, Dollars	Cumulative Initial Cost
1	1-1	2.10	32	15.2	24,000	24,000
2	4-1	4.00	54	13.5	41,000	65,000
3	5-3	2.50	32	12.8	26,000	91,000
4	4-2	3.60	45	12.5	43,000	—*
5	4-3	2.90	36	12.4	30,000	—*
6	2-1	3.50	43	12.3	43,000	134,000
7	1-3	3.20	45	11.8	37,000	147,000
8	5-4	3.80	42	11.1	40,000	161,000
9	2-3	2.80	29	10.4	35,000	—*
10	3-2	2.70	28	10.4	29,000	180,000
11	3-3	5.70	58	10.0	62,000	223,000
12	2-2	3.40	35	10.0	43,000	—*
13	1-4	4.10	53	8.9	47,000	233,000
14	3-1	4.20	38	6.7	46,000	—*
15	5-2	3.40	36	4.4	36,000	—*
16	5-1	4.60	44	2.5	48,000	241,000

*Not in optimal set of alternatives.

alternative is replaced by another within the same feature only if a greater benefit is produced by the second alternative. When that occurs, the cost of the first alternative is subtracted from the cumulative total and the cost of the second is added.

M&R alternative 1-1, line 1 of Table 26, is the most beneficial in the entire M&R program. It is also the first choice of the single feature optimization example given earlier in this section. If only $24,000 were available for the M&R program, alternative 1-1 would be the one to apply; the remaining features would not have any M&R.

As more money becomes available, additional high-benefit M&R activities can be added. If $65,000 were available, the best M&R program would use alternatives 1-1 and 4-1, the entries on lines 1 and 2 of Table 26; the total benefit would be 86. The best $91,000 M&R program uses alternatives 1-1, 4-1, and 5-3, the entries on lines 1, 2, and 3; the total benefit rises to 118.

Lines 4 and 5 do not represent the best choices of M&R alternatives since neither alternative 4-2 nor alternative 4-3 increases the benefit realized on the same feature by alternative 4-1, which is already part of the optimal set of alternatives at this budget level.

On line 6, another feature is added to the M&R program. A budget of $134,000 will fund alternatives 1-1, 2-1, 4-1, and 5-3. This raises the total benefit to 161.

On line 7, M&R alternative 1-3 can replace alternative 1-1 in the optimal set because it provides more benefit. The required budget of $147,000 will thus provide the maximum benefit with alternatives 1-3, 2-1, 4-1, and 5-3. The total benefit rises to 175.

The same reasoning can be followed through the table to line 16, where a maximum budget of $241,000 will provide the maximum possible benefit (252) in the M&R program by applying alternatives 1-4, 2-1, 3-3, 4-1, and 5-1.

This tabulation will always provide the maximum benefit at any specified budget level. One can see at a glance what budget level will provide optimal M&R alternatives and which alternatives should be avoided.

The original problem assumed that $170,000 is available for an M&R program (Table 24). By the time line 8 is reached in Table 26, a total of $161,000 would have to be spent on M&R alternatives 4-1, 2-1, 1-3, and 5-4, with no M&R alternative for feature 3. If another $10,000 were added to the M&R program, for a total of $180,000, alternative 3-2 could be applied to feature 3. If no more than $170,000 is available for the M&R program, it is best to do nothing to feature 3 and use only $161,000.

c. Output of the Incremental Benefit/Cost Algorithm

Table 26 follows the format used in the output of the incremental benefit/cost algorithm. The output table is advantageous because it gives at a glance the budget levels at which optimum sets of alternatives may be funded. Use of this procedure allows the consistent selection of the best M&R alternatives for all features included in an M&R program. Starting at the level of available funds, the decision-maker can scan the column of benefits and select, for each feature, the specific alternative that will make optimum use of the available funds.

A supplementary output table summarizes the best set of M&R alternatives for the specified budget level. Table 27, an example of this summary output, shows the results of the sample optimization problem for a maximum budget of $170,000.

TABLE 27. OUTPUT RESULTS OF EXAMPLE OPTIMIZATION PROBLEM

M&R Alternative	Annual Cost, Dollars per Square Yard	Annual Benefit	Initial Cost, Dollars
4-1	4.00	54	41,000
2-1	3.50	43	43,000
1-3	3.20	45	37,000
5-4	3.80	42	40,000

Total cost = $161,000
Total annual benefit = 184

SECTION X

CONCLUSION

This report documents development of APMS, a computerized system for analyzing airfield pavements. The system provides: (1) a method for determining possible M&R alternatives for a given pavement feature, (2) a procedure for performing economic analyses to compare various M&R alternatives for a given pavement feature, and (3) a procedure for forecasting PCI and key distresses as a consequence of applying an M&R alternative to a particular pavement feature.

APMS now consists of seven modules which are designed for the following functions:

1. Perform evaluation summary -- provides the user with a list of feasible M&R alternatives based on the results of pavement evaluation.

2. Perform localized repair analysis -- computes repair cost as well as PCI and distress after repair with a user-selected distress repair policy.

3. Evaluate consequence of localized repair -- forecasts the PCI for a given pavement feature after localized repair.

4. Evaluate consequence of other M&R -- forecasts the PCI for a given pavement feature after overall M&R, such as overlay or recycling.

5. Perform cost analysis -- computes the present value EUAC and the EUACSY for a given M&R strategy applied to a given pavement feature. These computations take into account both interest and inflation rates.

6. Perform benefit analysis -- computes benefits resulting from a given M&R alternative as measured by utility-weighted performance and adjusted for relative importance of the pavement feature (e.g., primary runway, secondary taxiway).

7. Perform budget optimization -- recommends M&R alternatives to be performed on a group of pavement features to maximize overall benefits from an assigned budget.

The APMS described in this report is the first generation of the system. The various modules have been under development for the past several years, and technology for some of the modules (e.g., module 4, above) is now being improved. The system has been carefully designed and computerized to incorporate this new technology as it becomes available. Field testing of the system by U.S. Air Force field personnel has already started.

REFERENCES

1. Shahin, M. Y., M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System, Volume I: Airfield Pavement Condition Rating, AFCEC-TR-27, Air Force Civil Engineering Center (AFCEC), November 1976.

2. Shahin, M. Y., M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System, Volume II: Airfield Pavement Distress Identification Manual, AFCEC-TR-27 (AFCEC), November 1976.

3. Shahin, M. Y., M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System: Volume III, Maintenance and Repair Guidelines for Airfield Pavements, AFCEC-TR-44 (AFCEC), October 1977.

4. Shahin, M. Y., M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System, Volume IV: Appendices A through I, Maintenance and Repair Guideline for Airfield Pavements, CEEDO-TR-77-44, Civil and Environmental Engineering Development Office (CEEDO), September 1977.

5. Shahin, M. Y., M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System, Volume V: Proposed Revision of Chapter 3, AFR 93-5, CEEDO-TR-77-4, (CEEDO), October 1977.

6. Shahin, M. Y., Development of a Pavement Maintenance Management System, Volume VI: Maintenance and Repair Guidelines -- Validation and Field Applications, ESL-TR-79-18 (Engineering and Services Laboratory (ESL), Air Force Engineering and Services Center (AFESC), December 1979.

7. Shahin, M. Y., M. I. Darter, and T. T. Chen, Development of a Pavement Maintenance Management System, Volume VII: Maintenance and Repair Consequence Models and Management Information Requirements, ESL-TR-79-18, December 1979.

8. McFarland, W. F. and D. T. Phillips, "Optimal Selection of Highway Accident Prevention Countermeasure," American Institute of Industrial Engineers Proceedings, 1979.